

# SCS STUDY REPORT - VOLUME 5

## SPACE STATION SIMULATION COMPUTER SYSTEM (SCS) STUDY for NASA/MSFC

# STUDY ANALYSIS REPORT

TRW-SCS-89-T2

31 October, 1989

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In accordance with the requirements of the subject contract, the final technical report titled SCS Study Report, consisting of six volumes is herewith submitted and distributed as shown.

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SPACE STATION SIMULATION COMPUTER SYSTEM (SCS)  
STUDY

STUDY ANALYSIS REPORT

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CDRL: TRW-SCS-89-T2

31 October, 1989

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## INTRODUCTION

The Simulation Computer System (SCS) is the computer hardware, software, and workstations that will support the Payload Training Complex (PTC) at MSFC. The PTC will train the Space Station payload scientists, station scientists, and ground controllers to operate the wide variety of experiments that will be on-board the Freedom Space Station.

This SCS Analysis Report summarizes the further analysis performed on the SCS Study as part of Task 2 - Perform Studies and Parametric Analysis - of the SCS Study contract. These analyses were performed to resolve open issues remaining after the completion of Task 1, and the publishing of the SCS Study Issues report.

The results of these studies provide inputs into SCS Task 3 - Develop and Present SCS requirements, and SCS Task 4 - Develop SCS Conceptual Designs. The purpose of these studies is to resolve the issues into useable requirements given the best available information at the time of the study.

Figure Analysis 1 gives a list of all the SCS study issues. The issues with a yes under the Further Study column are the ones discussed in this report. In some cases, one study was performed to address two issues. In these cases, the study number reflects the two issues addressed. Figure Analysis 2 shows the outline used to capture the results of the further analysis. This outline was developed at the beginning of the analysis, and was a great help in organizing the analysis effort. The text in *Venice Font on figure Analysis 2 describes the content of each section of the outline.*

MSFC is responsible for approving this SCS Analysis Report. TRW will assume MSFC approval of this report in the absence of any specific MSFC disapproval within 30 days of delivery of this report to MSFC. However, it is TRW's current intention to include this report as a chapter in the SCS Final Study Report, and thus any comments or additions that are relevant and important are solicited.

**Training Related Issues****Further Study?****Issue Number & Title**

Yes	T-1.	Scope of Payload Crew Training in PTC
No	T-2.	Scope of Ground Operations Personnel Training in PTC
Yes	T-3.	Scope of OMS Training in PTC
Yes	T-4.	Scope of Integrated Core Subsystem Training in PTC
No	T-5.	Fidelity of SS Payload Subsystems Simulations
No	T-6.	Fidelity of SS Experiment Simulations
No	T-7.	Fidelity of SS Experiment to System Interfaces
No	T-8.	Fidelity of SS Internal Data Flows Simulations
No	T-9.	Fidelity of SS Downlink and Uplink
Yes	T-10.	Fidelity of Element Control Workstation (ECWS)
No	T-11.	Support for Training Multiple Missions Simultaneously
No	T-12.	Support for Integrated Simulations with Other NASA Centers
Yes	T-13.	Support for Interoperable (Remote Executions) Simulations
No	T-14.	Requirements for SCS Interface with External Facilities
Yes	T-15.	Requirements for PTC Payload Video Data
No	T-16.	Requirements for Simulation Parameter Update Rate Requirements
No	T-17.	Requirements for High Rate Data Requirements
No	T-18.	Requirements for Virtual Instruments
No	T-19.	Requirements for Simplified Simulator Operations Setup and Control
Yes	T-20.	Support for Onboard Training

**Associated Development Issues****Further Study?****Issue Number & Title**

No	A-1.	Utilization of SSE Capabilities
No	A-2.	Techniques for Integrating and Maintaining PI-Provided Simulators
Yes	A-3.	Techniques for Supporting late changes to simulators
No	A-4.	Allowing Software Transportability between SCS and other centers
Yes	A-5.	Techniques for Integrating Flight Hardware/Software with SCS Simulators
Yes	A-6.	Flexibility for Allowing Advanced Technology Insertion
Yes	A-7.	Implications of Simulation Development Cycle
Yes	A-8.	Sizing Growth Potential in Capability/Capacity
No	A-9.	Defining Telemetry Data Format and Calibration
Yes	A-10.	Fidelity of DMS Interface
Yes	A-11.	Definition of "No single point of failure"
No	A-12.	Requirements for Interfaces with SOAN and SSIS
No	A-13.	Requirements for Configuration Management of Simulation Software
Yes	A-14.	Definition of GSE-Provided Services

Figure Analysis 1. List of SCS Study Issues

Study Title: Same title of the issue that requires further study.

Study No. Same number as the issue.      Report Version:

#### Problem

Explains the problem, and it's relevance to SCS.

#### Approach

A brief description of what analysis was done to resolve the problem.

#### Analysis Overview

Summarizes the analysis so that the details below are understandable.

#### Inputs

Documents or other information used in the analysis.

#### Assumptions

Assumptions made for unknowns or TBDs used in the analysis.

#### Analysis

A description of what was done and how it was done to further analyze the problem - used formulas, graphics, consulted documents like Architecture Control Documents, Functional Control Documents, other Specifications, or consulted people. Results will be shown with the analysis for clarity, unless it is clearer to summarize them only at the end.

#### Results

A summary of the results. Includes candidate requirements.

#### Open Issues/Notes

Any further issues still unresolved. There should be very few of these.

**Figure Analysis 2. Outline Used in Further SCS Study Analysis**



**Study Title:** **Scope of Payload Crew Training in PTC**

**Study No. T-1** **Report Version: 6**

### Problem

The load on the PTC simulation computer system was estimated by Study T-1 (for payload simulations) in early 1989. Since then, efforts have been made to provide better definition for the payloads comprising a typical SS complement. This later version of study T-1 will make use of more recent information now available to obtain the best possible estimate at this time of the required on-line capacity of the SCS due to payload simulations.

### Approach

An analysis of a "typical" payload complement for the US Lab will be performed to determine the maximum loading on the SCS at any given time to support payload training.

Analysis will include classifying SS payloads into three levels of simulator complexity and then determining CPU sizing requirements using Spacelab payload simulators of comparable complexity that have been developed for the Spacelab training program at the PCTC as a benchmark. This loading will include requirements for attached payloads as well as laboratory module experiments. The loading requirements for a single mission will then be factored by the total SS payload training, operations evaluations, and development functions that are anticipated to be occurring simultaneously during the SS life cycle to determine the total SCS load requirements.

### Analysis Overview

The Multilateral Utilization Study (MUS) was used as the source for a typical payload complement in the US Lab for a typical SS mission. The payload complement included Materials Science, Life Science, Technology, and Attached payloads. Each payload experiment was analyzed based on data flow, video, command control requirements, and potential interfaces to SS subsystems such as power and environmental control, in order to classify each experiment into one of three categories of complexity with respect to their simulation load on the SCS.

### Inputs

1. Multi-lateral Utilization Study (MUS) Integrated Data Package for Third Quarter Studies - 2/24/89.
2. Operational Timelines for OAST Technology Payloads in the MUS Allocated Set
3. Interviews with Annette Sledd/ Utilization - EL14, Donna Odom/Boeing-Customer Utilization, Larry Torre/Boeing-Customer Utilization, and Charles Gartrell/OAST.

4. PCTC Experiment Simulator Requirements and Simulator Design Development Handbook, JA-711, July 15, 1987.

#### Assumptions

1. A worst case load on the SCS is assumed for payload models which might be simulated by either physical hardware or a simulator executing on the PTC SCS.
2. Code size estimates are based on Spacelab experience using structured analysis and FORTRAN coding. These estimates may be reduced using new CASE tools and new programming methodologies.
3. The US Lab payload complement is considered to include all payloads in the US Lab, US Node, plus External Experiments controlled from the US Lab or Node.

#### Analysis

#### Multi-lateral Utilization Study Payload Complement Review and Classification

The payload complement of the mission planning exercise included the following experiments:

##### Materials Science Experiments

1. Space Station Freedom Furnace Facility
2. Modular Containerless Processing Facility
3. Commercial Protein Crystal Growth Facility
4. Fluid Physics/Dynamics Facility
5. Modular Combustion Facility
6. Commercial Vapor Transport Facility
7. Commercial Organic/Polymer Facility
8. Commercial Float Zone Facility

##### Technology Experiments

1. Quantized Vortex Structures in Superfluid Helium
2. Solar Array Energy Storage Technology
3. Surgery Technology Development

##### Life Science Experiments

1. Habitat Holding System
2. Multiple Generation Plant Growth
3. Muscle Loss in Rats
4. Structural Changes in the Rat's Labyrinth
5. Space Radiation Effects on Spermatogenesis and Intestinal Villi
6. Retinal Imaging
7. Radiation Field Characterization
8. Cardiac Electrophysiology
9. Mechanisms of Orthostatic Intolerance
10. Blood Erythrokinetics
11. Myocardial Changes in Rodents

#### Attached Payloads

1. Dynamics Stabilization Free-Flyer Robot
2. Optical Spatial Tracking Spacecraft
3. Spacecraft Strain and Acoustic Sensors
4. Low Acceleration Propulsion Technology
5. Microelectronics Data System Experiment
6. Advanced Structural Dynamics and Control

#### MATERIALS SCIENCE EXPERIMENTS

Space Station Furnace Facility - The Space Station Furnace Facility (SSFF) is a modular facility for materials processing experiments involving metals, glasses, ceramics, crystal growth, and electronic/photonic materials. The SSFF is composed of 5 double racks; one for experiment control and support, and 4 for exchangeable furnace modules. Nine different modules are planned:

- a) High-Temperature-Gradient Directional Solidification Furnace Module. Samples will be processed under very precise temperature and translation control conditions.
- b) Low-Temperature-Gradient Directional Solidification Furnace Module. Samples processed under very precise temperature and control conditions.
- c) Large Bore Low-Temperature-Gradient Directional Solidification Furnace Module. For larger samples.
- d) Vapor Crystal Growth Furnace Module. Thermal and optical sample monitoring.
- e) Isothermal/Rapid Solidification Furnace Module. Complex sample geometries.
- f) Hot Wall Float Zone Module. Quasi-containerless sample processing with optical and thermal imaging of the molten zone and solidification interface.
- g) Gradient Freeze Furnace Module. Controlled linear thermal gradient through samples.
- h) High Pressure Furnace Module. Directional solidification or casting at high vapor pressures.
- i) Thermophysical Property Measurement Furnace. Optical viewing of samples for the UV to mid-IR wavelengths, and Laser Holography/Doppler effects.

Command and telemetry data between the ground and the Furnace Controller is estimated at 1 kbps nominal, and 14 kbps peak. Data rates from the experiments vary between .5 and 3.0 kbps per experiment. It is assumed that there will be a maximum of 5 experiments operating simultaneously.

The simulator for the SSFF will have interface requirements to power, environmental control, and PMMS subsystem simulations. The Facility Controller will store experiment timelines, issue commands, perform control and monitoring of the experiments, and acquire and store data. Based on these factors, the Space Station Furnace Facility controller is considered to be complex with respect to the SCS load. In addition, the nine furnace modules are considered to provide an additional SCS load of simple complexity each.

Modular Containerless Processing Facility - The Modular Containerless Processing Facility (MCPF) will accommodate experiments where the sample is not in physical contact with the container walls. Samples (liquids, solids, aerosols) will be positioned using acoustic, electrostatic, and magnetic fields. Heating is provided by combinations of electric furnace, light beam, and laser beams.

The facility will include two double bay racks for active experimentation. These will accommodate a combination of high and low power experiments. It is anticipated that the facility will utilize an initial set of 4 experiment modules. Only one high power experiment may run at one time, but it may run concurrently with lower power experiments. The simulator is assumed to be capable of running a maximum of one high power, and one low power experiment simultaneously. All microprocessor

experiment control is assumed to reside in the Facility, rather than with the individual experiments.

Continuous digital data is needed to command and monitor the facility. The data interface for housekeeping functions will function at 80 kbps for both uplink and downlink. Media standard video, as well as high resolution video will be required for setup and monitoring of some experiments. Audio links will be used during periods of crew interaction.

The MCPF will utilize electric power, water and air cooling, and nitrogen for module purges. Gas venting to the PMMS is also required.

The MCPF simulator will have interfaces to power, environmental control, and PMMS subsystem simulations. Modeling of housekeeping parameters is considered a non-trivial requirement based on the 80 kbps estimated traffic for such parameters. Microprocessor control of various heating, cooling, and positioning facilities for the experiments is also considered non-trivial. Based on the above factors, this simulator is considered to be complex with respect to the SCS load. In addition, each of the four experiment modules is considered to impose an additional load on the SCS of simple complexity each.

Commercial Protein Crystal Growth Facility - The Protein Crystal Growth Facility (PCGF) is a temperature controlled, microgravity environment for growing protein crystals. The facility includes a number of individual protein growth cells, temperature control and monitoring system, power conversion system, and a video camera with fiber optic interface. It is assumed that a microprocessor controls the temperature, and monitors the sample temperatures, power, and other housekeeping parameters. Downlink for non-video data is nominally 1.5 kbps.

The SCS load for this facility will be limited to interfaces with power and environmental control subsystem simulations; simulation of the processor/controller functions, and some health and feedback status parameters. Based on these factors, this simulator is considered to be of medium complexity with respect to the SCS load.

Fluid Physics/Dynamics Facility - The Fluid Physics/Dynamics Facility (FP/DF) will accommodate experiments to help develop understanding of the fundamental theories of fluid behavior, provide improvements in thermophysical property measurement and to provide data helpful to fluids-related applications/systems. The facility will consist of a Facility rack, and one or more interchangeable Experiment racks.

The Facility rack will house the user support systems, including a DMS data interface capable of communicating 160-250 kbps telemetry downlink, and 20kbps uplink. The Facility rack will also enable high resolution, high frame-rate video data (2100 mbits/sec bursts). Experiment control will be primarily from the Element Control Workstation, with occasional local control at the facility using a portable MPAC.

The Experiment rack(s) will be interchangeable, each housing a specific experiment type. Potential racks could contain dynamic fluid experiments in a Multi-Phase Flow Apparatus, or static experiments in a vibration isolated containment enclosure. Other potential experiment types involve acoustic levitation facilities, a cryostat, and equipment enabling high temperature processes. Various experiment sections or sealed cells would be available to fit into each type of rack for the various experiment runs.

It is assumed that the FP/DF will be capable of hosting two simultaneous experiments, each under microprocessor control from the Facility rack. In addition, the

Facility rack will perform support functions such as on-board data and video processing. Both racks will require interfaces for electrical power, ECLSS air-cooling, TCS interfaces for cold-plate-cooled and integrally cooled hardware. The Experiment rack will require PMMS interfaces for a variety of fluids and to vent waste fluids.

The FP/DF simulator will have interface requirements to power, environmental control, and PMMS subsystem simulations. Data simulation will be required for housekeeping status data such as electric current, flow rates, and temperatures. The simulator must support training functions for the Power Control System, Process Controller, Data Recorder and Video System. Based on these factors, and the required support and control functions for the experiments, the Fluid Physics/Dynamics Facility simulator is considered to be complex with respect to the SCS load. In addition, each of the five potential experiment types is considered to provide an additional SCS load of simple complexity.

Modular Combustion Facility - The Modular Combustion Facility (MCF) will accommodate experiments to help develop understanding of the fundamental theories of combustion processes and phenomena, and to provide data helpful to combustion related applications such as spacecraft fire safety. The facility will consist of a Facility rack, and one or more Experiment racks.

The Facility rack will house the user support systems, including a DMS data interface capable of communicating 160-250 kbps telemetry downlink, and 20kbps uplink. The Facility rack will also enable high resolution, high frame-rate video data (2100 mbits/sec bursts). Experiment control will be primarily from the Element Control Workstation, with occasional local control at the facility using a portable MPAC.

The Experiment rack(s) will be interchangeable, each housing a specific experiment type. Potential racks could include a Combustion Chamber and a very low speed Combustion Tunnel. Various sets of combustion apparatus for the Chamber, and test sections for the Tunnels would be available for the various experiment runs.

It is assumed that the MCF will be capable of hosting one experiment at a time, under microprocessor control from the Facility rack. In addition, the Facility rack will perform support functions such as on-board data and video processing. Both racks will require interfaces for electrical power, ECLSS air-cooling, TCS interfaces for cold-plate-cooled and integrally cooled hardware. The Experiment rack will require PMMS interfaces for a variety of fluids and to vent waste fluids.

The MCF simulator will have interface requirements to power, environmental control, and PMMS subsystem simulations. Data simulation will be required for housekeeping status data such as electric current, flow rates, and temperatures. The simulator must support training functions for the Power Control System, Process Controller, Data Recorder and Video System. Based on these factors, and the required support and control functions for the experiments, the MCF simulator is considered to be complex with respect to the SCS load. In addition, the two types of experiment setups is considered to provide an additional SCS load of simple complexity each.

Commercial Vapor Transport Facility - The Vapor Crystal Facility consists of multiple special gradient furnaces with individual micro-processor control for production of diffusion gradients and vapor transport. The facility has data requirements of 800 - 4000 bits/second and includes more than 50 analog temperature, pressure, and other housekeeping parameters from four simultaneously operating experiments. The

simulator must support training functions for the microprocessor/controller with display and keyboard, video/fiber optical diagnostic system, gas/vacuum distribution and control system, and the heat rejection/cooling system. The microprocessor unit interfaces with thermal and pressure transducers, power supplies, gas supply solenoid valves, purge solenoid valves, and cooling loop control valves. It is capable of storing operational parameters and varying the power to the heating elements to maintain the desired environment. The optical diagnostic system includes a stereo microscope, a high resolution video camera, and light scattering devices. The facility will support four simultaneous experiment operations and thus includes four microprocessors, four heat exchangers, and one optical diagnostics system.

Based on these factors the Vapor Crystal Facility is considered to be a complex simulator with respect to the SCS load. In addition each of the 4 individual experiment microprocessors is considered to provide an additional SCS load of medium complexity each.

Commercial Organic and Polymer Crystal Growth Facility - The Organic and Polymer Crystal Growth Facility (OPCGF) will provide a standard interface and support for a set number of NASA or customer-supplied growth modules. These modules will enable the growth by various means, of organic and polymeric crystalline materials. The facility will provide power, confinement, and the capability for materials processing, data acquisition and recording, control, and diagnostics. The facility consists of a double rack of equipment, including 4 experiment modules, a control unit/recorder, and a melt-growth furnace containment. It is assumed that the facility will accommodate two simultaneous experiments at one time. Data downlink is estimated in the range of 1-5 kbits/sec.

The simulator for the OPCGF will include interfaces with power and PMMS subsystem simulations. It will simulate the processor/controller/recorder functions and, based on the small telemetry flow, will have to simulate a relatively small number of operational and status parameters. From these factors, the OPCGF simulator is considered to be of medium complexity with respect to the SCS load. In addition, each of the 4 individual experiment processors is expected to represent an additional SCS load of simple complexity each.

Commercial Float Zone Facility - The Commercial Float Zone Facility (CFZF) consists of a single rack containing two axial tube furnaces with temperature capabilities up to 1600 degrees C. Between the two tube furnaces is an independently-controlled high temperature zone capable of up to 2200 degrees C. The furnace system is capable of holding a sample just below its melting point, except for a molten zone in the center which can be translated along the sample length by the movement of the furnace. Data generation during a run is estimated at 250 bps.

The CFZF simulator will provide interfaces to the power, PMMS, and environmental control subsystem simulations. It will simulate the processor/controller functions of the facility and a small number of housekeeping parameters. Based on these factors, the CFZF is considered to represent a load of simple complexity to the SCS.

## TECHNOLOGY EXPERIMENTS

Quantized Vortex Structures in Superfluid Helium - This experiment will investigate the formation and distribution of quantized vortices in freely suspended rotating drops of superfluid helium. An acoustic suspension system will be used to suspend a drop of liquid helium within a cryostat at 2 degrees Kelvin. While rotating the drop, vortices within the drop will be observed optically with low and high resolution cameras. Nominal data generation rates are estimated at 100 kbps. The experiment functions include:

- Cryogen Facility controls
- Cryostat control
- Acoustic Suspension System controls

The simulator for this experiment must provide interfaces to power, PMMS, and environmental control systems. Some simple scene generation capability will probably be necessary. The simulator will model the processor/controller functions of this experiment, and generate a number of housekeeping/status parameters. Based on the above factors, this simulator is considered of medium complexity with respect to the SCS load.

Solar Array Energy Storage Technology - The purpose of the Solar Array Energy Storage Technology (SAEST) experiment is to demonstrate various power system technology applications in space. The experiment equipment, consisting of a power experiment application such as an Energy Storage Unit, and a controller/monitor panel, takes up about 60% of one rack. Nominal data generation during an experiment run is estimated at 1000 kbps for 20.4 hours. The simulator for this experiment will generate some housekeeping parameters of the experiment, and simulate the control and monitor functions, possibly interactive with table-generated science data. Based on these factors, this simulator is considered to be of medium complexity with respect to the SCS load.

Surgery Technology Development - The purpose of this experiment is to develop a surgical module, and surgical procedures effective in microgravity. Experiment hardware will take up two racks and consist of a surgical table; patient, doctor, and tool restraints; a fluid containment system, lighting, fluid suction apparatus and surgical implements. The facility will probably be composed of PI-supplied equipment, requiring little or no simulation support. There are no apparent data communication requirements with the ground, so simulation of housekeeping data parameters are not a concern. All data collection will be handled with Lab Support Equipment or facilities of the Surgery Technology Experiment. Therefore, this experiment is not considered to represent a significant simulation load to the SCS.

## LIFE SCIENCE EXPERIMENTS

The Life Science Experiments are not anticipated to, in general, require any simulation capability from the SCS. They will mainly involve measurements of crewmembers' physiological characteristics, dissection of lab animals, and other activities involving Lab Support Equipment whose load on the SCS has been calculated in Study T-4. Many experiment simulators will consist primarily of PI-



supplied equipment requiring relatively little simulation support. Exceptions are noted below:

Habitat Holding System - The rodent habitat equipment will have some environmental support type data parameters which may require simulation via the SCS. Types of data that shall be acquired, processed, and made available for monitoring will include:

- The amount of food and water consumed, and the amount of physical activity performed by the specimen.
- Excess water indicators which monitor the water distributed to the system.
- Critical instrument temperatures and humidity measurements.
- General housekeeping data of the RAHF.

This equipment is considered to be similar to the Spacelab Research Animal Holding Facility (RAHF) experiment and is considered a medium complexity experiment with respect to the SCS load.

Bioregenerative Life Support Facility - The purpose of this experiment is to determine the microgravity conditions for optimizing plant productivity. It will consist of 8 habitats for plants; two at 1-g on the centrifuge, and 6 at 0-g. There will be inflight telemonitoring and control of the plant habitats. Nominal data generation is estimated at 256.0 kbps. The simulator for this experiment will have interfaces to power and environmental control. In addition, the simulator will probably generate environmental support type data parameters for the habitats. Based on the above factors, this experiment is estimated to represent an additional SCS load of medium complexity.

### ATTACHED PAYLOADS

Dynamic Stabilization Free Flying Robot - The goals of this experiment are to evaluate techniques of dynamically stiffening the relative position and orientation of a free-flying robot while servicing another flying article. Another goal is to characterize the dynamic interactions of two moving objects in a zero-g environment.

This experiment will use a free-flying robot and two test articles. The robot will perform sample operations such as module replacement on the test articles, while the performance of its position and attitude stiffening control system will be measured, as will the dynamic interaction characteristics.

The experiment-specific equipment with which the crew will interact during the experiment includes data processors, CRTs, data recorders, signal analyzers, monitor/control units, etc. Typical IVA tasks will include monitoring the robot, providing contingency commands, and recording data. Besides the specialized experiment panels, the experiment requires the use of the Telerobotics Workstation, the APAE Workstation, and the OMV Workstation. There will be nominal data-flows of 90 kbps for downlink, 10 kbps for uplink; 20 kbps from Station to Free Flyer, and a video link from the Free-Flyer to the Station. There will be an interactive audio link between the Station and Ground.

The simulator for this experiment must supply interactive video data, operations of signal analyzers and monitor/control functionality. There will be interactive man-in-the-loop type simulations necessary. A significant number of housekeeping parameters will have to be simulated. Based on the above factors, this simulator is considered to be complex, with respect to the SCS load.

Optical Spatial Tracking Spacecraft - The Optical Spatial Tracking Spacecraft (OSTS) is an experiment which will verify the accuracy of current super resolution optical techniques of locating distant spacecraft. The experiment will verify the operability of the technique's measurement capability, and assess the impact of the Space Station environment on that capability.

The primary experiment equipment will consist of externally mounted optical/electronic instruments which will be focused on two OMV-mounted laser sources. The control and observation equipment for this experiment will be contained in a half rack in the US Lab at a specialized experiment panel. The OMV Workstation will be used to maneuver the OMV, while the APAE Workstation will be used for external payload-common activities such as data routing. While configuration of the specialized experiment panel is not yet well defined, it will probably consist of controls and displays sufficient for:

- Pointing of optical instruments
- Power control
- Video recording
- Data recording

Data communications with the earth are estimated at 1000 kbps downlink and 32 kbps uplink, plus interactive audio communications. Pointing experiments of this type usually require a lot of computer simulation support, due to the man-in-the-loop, interactive type of simulations necessary for training. In addition, a significant number of housekeeping parameters will probably need to be generated. Based on these factors, this simulator is considered to be complex with respect to the SCS load.

Spacecraft Strain and Acoustic Sensors - This is an external experiment, requiring little crew interaction, beyond a very small amount of monitoring at the experiment panel. The simulator will be required to generate housekeeping parameters for the experiment sensors and equipment, and provide nominal science data values to an instrument or display. Based on the above factors, this experiment is considered to be of simple complexity with respect to the SCS load.

Others - The following external experiments, while considered part of the Mission Utilization Study payload complement, do not represent a unique load to the SCS, since their operation will be controlled from Station systems:

- Low Acceleration Propulsion Technology
- Microelectronics Data System Experiment
- Advanced Structural Dynamics and Control

SS Payload Review and Classification Summary - The above described analysis of a typical SS payload experiment complement indicates the following mixture of payload simulators will be required for a single SS mission increment.

	<u>Complex</u>	<u>Medium</u>	<u>Simple</u>	<u>Total</u>
U.S. Lab	5	10	25	40
<u>Attached Payloads</u>	<u>2</u>	<u>0</u>	<u>1</u>	<u>3</u>
Total	7	10	26	43

These numbers represent the load required for the individual experiment payload simulators. In addition host service software tasks will be required to provide the total simulation environment. The Spacelab payload training environment can be used as a representative example of the additional host system overhead required to provide the total simulation environment. The following is an example list of Spacelab PCTC host system level tasks.

Task

OIT - Operator Control Task (OCT) Initialization Task  
 ACP - Asynchronous Command Processor  
 AKP - Asynchronous Keyboard Processor  
 SDP - Simulation Display Processor  
 AMP - Asynchronous Message Processor  
 SS0-SS4 - Synchronous Task Schedulers  
 ECPREP - Experiment Computer Preparation Task  
 GMT - Time Generation Task  
 ECOS0 - Command Processor  
 ECOS1 - Keyboard Message Processor  
 ECOS2 - Display Processor  
 ECOS3 - Timeline Services Task  
 ECOS4 - Exception Monitoring Task  
 KBDSERVx - Keystroke Processor Task (one for each workstation)  
 DSPVS11 - Display Servicer Task  
 XTLM - Timeline Maintenance Task  
 XTMN - Timeline Monitor Task  
 ENV - Orbiter Environment Model  
 EPDS - Electrical Power Distribution Simulator  
 HRZS - Horizon Sensor Simulator  
 VTR - Video Tape Recorder Simulator  
 VAS - Video Analog Switch Simulator  
 OFD - Orbiter Flight Data  
 PTC - Payload Thermal Control  
 PLSS - Payload Status Simulator

In the Spacelab training environment these types of host level tasks provide an additional computer system execution load of approximately 48,200 lines of code and 2500 K bytes of memory. Note that the development load for the host system task could be considerably higher (up to 220,000 lines of codes) but this would include various library routines and tasks that would not be required to execute during a training session. All of these tasks would be required to execute in a one second

execution cycle. In addition to these host level requirements, some level of software simulation of DMS capability may be required. If, for example, DMS components were late, or unavailable, a DMS simulation would be critical. For estimating purposes this level is assumed to be approximately the same as the host system level load described above.

### SCS Loading

To determine the SCS load in terms of memory requirements and lines of code, comparable Spacelab payload experiments were used as a benchmark. The following table shows some size requirements for typical Spacelab payload models.

<u>Model</u>	<u>Complexity</u>	<u>Lines of Code</u>	<u>Memory Requirements(K bytes)</u>
HUT	Complex	47,300	172
WUPPE	Complex	49,300	180
UIT	Complex	44,900	151
IMCS	Medium	21,100	90
JOP	Medium	22,900	120
A7PNL	Simple	4,200	47
OFD	Simple	11,400	102
1ES013	Complex	26,100	402
1ES016	Simple	11,400	193
1ES017	Simple	6,400	154
AEPI	Complex	16,600	454
SEPAC	Complex	24,000	513
ISO	Simple	3,100	106
FAUST	Simple	6,400	92
Average Complex		34,700	312
Average Medium		22,000	105
Average Simple		7,150	116

Using these average numbers and the above payload model classification list provides a total SCS load for the US Lab and Attached Payloads (a combined payload training configuration) of:

	Lines of Code	Memory Requirements (K bytes)
7 complex models @34700 = 242,900		@312 = 2,184
10 medium models @22000 = 220,000		@105 = 1,050
26 simple models @7150 = 185,900		@116 = 3,016
Host system tasks = 48,200		= 2,500
DMS S/W Simulation = 48,200		= 2,500
Combined P/L Total	745,200	11,250

If we assume that the combined Columbus/JEM module payload complement would be approximately equal to the US Lab SCS load we can estimate the total SCS load for one SS consolidated increment as follows:

	Lines of Code	Memory Requirements (K bytes)
14 complex models @34700 = 485,800		@312 = 4,368
20 medium models @22000 = 440,000		@105 = 2,100
52 simple models @7150 = 371,800		@116 = 6,032
Host system tasks = 48,200		= 2,500
DMS S/W Simulation = 48,200		= 2,500
Increment Total	1,394,000	17,500

Based on the assumption that a part task trainer will support one third the payload complement (plus the system overhead) of a combined payload trainer complement, the following numbers can be derived for a part task trainer:

	Lines of Code	Memory Requirements(K bytes)
2 complex models @34700 = 69,400		@312 = 624
3 medium models @22000 = 66,000		@105 = 315
8 simple models @7150 = 57,200		@116 = 928
Host system tasks = 48,200		= 2,500
DMS s/w simulation = 48,200		=2,500
Part Task Trainer Total	289,000	6,867

Figure T-1.1 shows the PTC Training Increment Flow Requirements for all the SS missions that will be in the training flow at one time. From this figure it can be seen that the PTC must support crew training on 4 different missions simultaneously. This will include one full consolidated increment training configuration, one combined P/L training configuration, and part task training or individual P/L training on experiments from two other increments. The baseline assumption is that there can be three part task training configurations operating simultaneously for the purpose of training. Others will be operating for simulator development, simulator I&T, simulator V&V, and simulator maintenance. Also shown is the POIC training in payload operations that must be supported. The above estimates and the PTC training increment flow requirements from Figure T-1.1 can be used to determine a total SCS training load requirement as follows:

	Lines of Code	Memory Requirements (K bytes)
1 Consolidated @1,394,000 = 1,394,000 Increment Configuration		@17,500 = 17,500
1 Combined P/L @745,200 = 745,200 Configuration		@11,250 = 11,250
3 Part Task @289,000 = 867,000 Configurations		@6,867 = 20,601
1 POIC Configuration (7 consoles)	1,394,000	@17,500 = 17,500
SCS Training Total	<u>4,400,200</u>	<u>66,851</u>

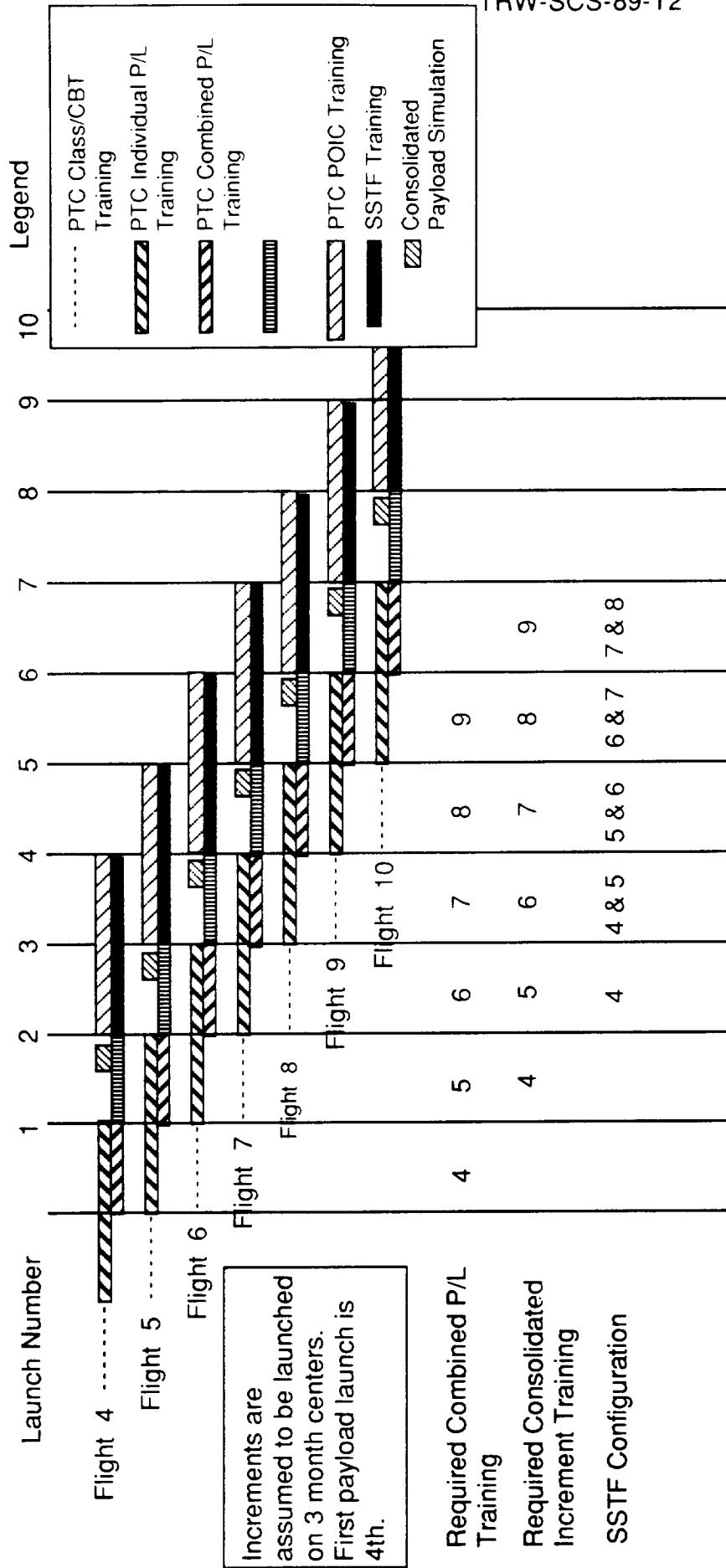


FIGURE T-1.1 PTC TRAINING INCREMENT FLOW REQUIREMENTS

## Results

1. The SCS (to determine the training portion of the load on the system) shall support the simultaneous execution of 6 independent training systems (1 full consolidated increment trainer, 1 combined payload trainer configuration, 1 set of 7 POIC training consoles all running the same increment, and 3 part task trainers).
2. An increment trainer can be assumed to consist of a total of 1,394,000 lines of code and 17,500 K bytes of memory.
3. A combined payload trainer configuration can be assumed to consist of a total of 745,200 lines of code and 11,250 K bytes of memory.
4. A part task trainer can be assumed to consist of a total of 289,000 lines of code and 6,867 K bytes of memory.

## Open Issues/Notes



**Study Title: Impact of OMS Training Support on PTC****Study No. T-3** Report Version: 2Problem

The PTC will train flight and ground crews in payload management activities which require the use of OMS functions for their proper execution. The impact on SCS requirements of providing the necessary OMS functionality and training must be determined.

Approach

An analysis of OMS functions will be performed to determine their effect on the SCS functions of training, development, and operations evaluation. While detailed OMS responsibilities for payload management are not yet available, top level functional requirements have been defined for general OMS operations. These requirements will be individually assessed to determine the impact on the SCS configuration of providing appropriate training for their payload-related aspects.

Analysis Overview

The Operations Management System (OMS), will provide management of operations requiring coordination between Space Station Systems, Elements, Payloads, and the ground and flight crews. The OMS will be composed of onboard application software (the Operations Management Application (OMA)) resident in the DMS as well as ground application software (Operations Management Ground Application (OMGA)). For training purposes, the OMA software functions are assumed to be provided by supplied DMS kits. The OMGA functions may have to be simulated by the SCS.

DMS kits and their effect on SCS requirements have been considered in study A-10. This study will assess only the impact of OMS-unique payload management training requirements on the SCS configuration.

Inputs

1. SSP 30000 Space Station Program Definition Requirements Document, Section 3, Revision G
2. JSC 32060 Space Station Training Facility (SSTF) Level A Simulation Requirements
3. SSP 30261 Architectural Control Document, Data Management System, Revision B, Feb. 19, 1988

### Assumptions

3. OMS functionality with respect to the onboard application (OMA) will be provided by the flight software resident on the DMS kits. OMS functionality with respect to the ground application (OMGA) will not be a part of the DMS and will have to be provided by other means.

### Analysis

The primary purpose of the PTC is to provide training in payload operations. In order to do this however, it is also necessary to teach the utilization of support and implementation systems ancillary to payloads (such as the OMS). Since it is assumed that trainees will receive basic instruction elsewhere on these systems, PTC instruction will most likely be strictly procedural in nature, involving system tasks directly supportive of the payload activity addressed. The problem then, is not so much to determine the impact of providing training for payload-unique OMS functions, but rather the impact of providing the simulated OMS environment which will be necessary for the execution of simulated payload operations.

Since the OMGA is not expected to be hosted on the DMS, it will not be available on a DMS kit. This means that the OMGA functions will be derived either from a WP-02 simulation, an SCS-developed simulation, or the actual ground software. OMA functions on the other hand, will be derived from the software resident on the provided DMS kits. For both parts of the OMS, consideration must be made for the SCS requirements to interface, integrate, and operate the required OMS/DMS functionality.

OMS top level functions are analyzed to determine the necessary interfaces with the flight crew, ground crew, payloads, and SS systems which must be simulated in the PTC. A review of OMS documentation shows that the OMS is currently expected to provide the following services:

1. Manage and update the short term plan
2. Coordinate systems, payloads, and crew operations in execution of the short term plan
3. Monitor systems and payload status
4. Manage inter-system testing
5. Maintain and log global configuration, activity, and state information
6. Detect and manage resource conflicts
7. Manage global base caution and warning
8. Perform global base fault management and reconfiguration
9. Support transaction management
10. Provide global base inventory and maintenance management
11. Support onboard simulation and training

The level of detail available for the above activities is insufficient to allow their decomposition into payload related and non-payload related components. Analysis of the above services however, does yield the minimum dataflows and interfaces required for the OMS to accomplish its payload-related tasks (see Figure T-3.1). Figure

T-3.2 consolidates those dataflows and depicts the interfaces, implemented with SCS simulations and a DMS kit.

Major interface #1 links onboard and ground OMS software via the C&T system. Onboard OMS can be simulated by the flight software resident in the DMS kit. The ground OMS however, as well as the linking C&T function (or data transformations necessary to mate OMGA software with the DMS flight data streams), must be provided by the SCS.

Major interface #2 links the OMS with the flight crew workstations. Since the crew workstations are included as part of the DMS kit, no SCS interface is required.

Major interface #3 links the OMGA with the other POIC functions. This interface is internal to the SCS but for fidelity may have to be implemented in a manner analogous to the real world application, the details of which are not currently defined.

Major interface #4 links the OMA with SS payloads, elements and systems. At the PTC, this refers to the interface between the DMS kit and SCS-resident simulations as well as to flight or flight-equivalent hardware/software. While communications between these simulations and the OMS will require special SCS interfacing, most of this effort is due to the necessity of linking with the DMS kit, rather than a unique requirement imposed by the OMS. It is likely however, that more fidelity will be required of the SS subsystem simulations in order to provide the OMS with the data necessary for the execution of its management functions.

## Results

These study results are based on the most current OMS information available. There are however, efforts being made to more fully define the payload management role of the OMS. A NASA study, in conjunction with McDonnell Douglas and TRW has been recently initiated to determine requirements in this area. Immediate efforts are also underway to redefine plans for POIC-resident software, including the OMGA. The SCS study will track developments in these areas and assess their impact on SCS requirements.

## Training

In order to train payload operations which require OMS services:

1. An OMGA simulation, and its interface with the DMS kit and the other POIC functions must be provided. Since preliminary estimates have sized the onboard OMS at 2.5-3.2 MIPS and 14.4-21.0 MB of memory, and considering that one function of the OMGA is to serve as an OMA backup, the load on the SCS imposed by the OMGA may be assumed to be about 3.2 MIPS and 32 MBytes of common storage (not including the DMS interface, which would have to be provided in any case).
2. SS simulations executed in the SCS will need to be more complex in order to supply the data and response required by the OMS management functions. An increase in complexity (and resultant SCS load) of at least 20% for each module is

foreseen over that needed to satisfy strictly payload requirements. It is not certain however, if this represents an increase in the fidelity requirements already envisioned for SS system simulations (reference Issue T-5). In the case of payload simulations, command/response requirements would be unaffected by the presence of an OMA interface and experiment data streams could still be statically simulated; therefore no significant increase in complexity over that already estimated (Issue No. T-6) should be necessary.

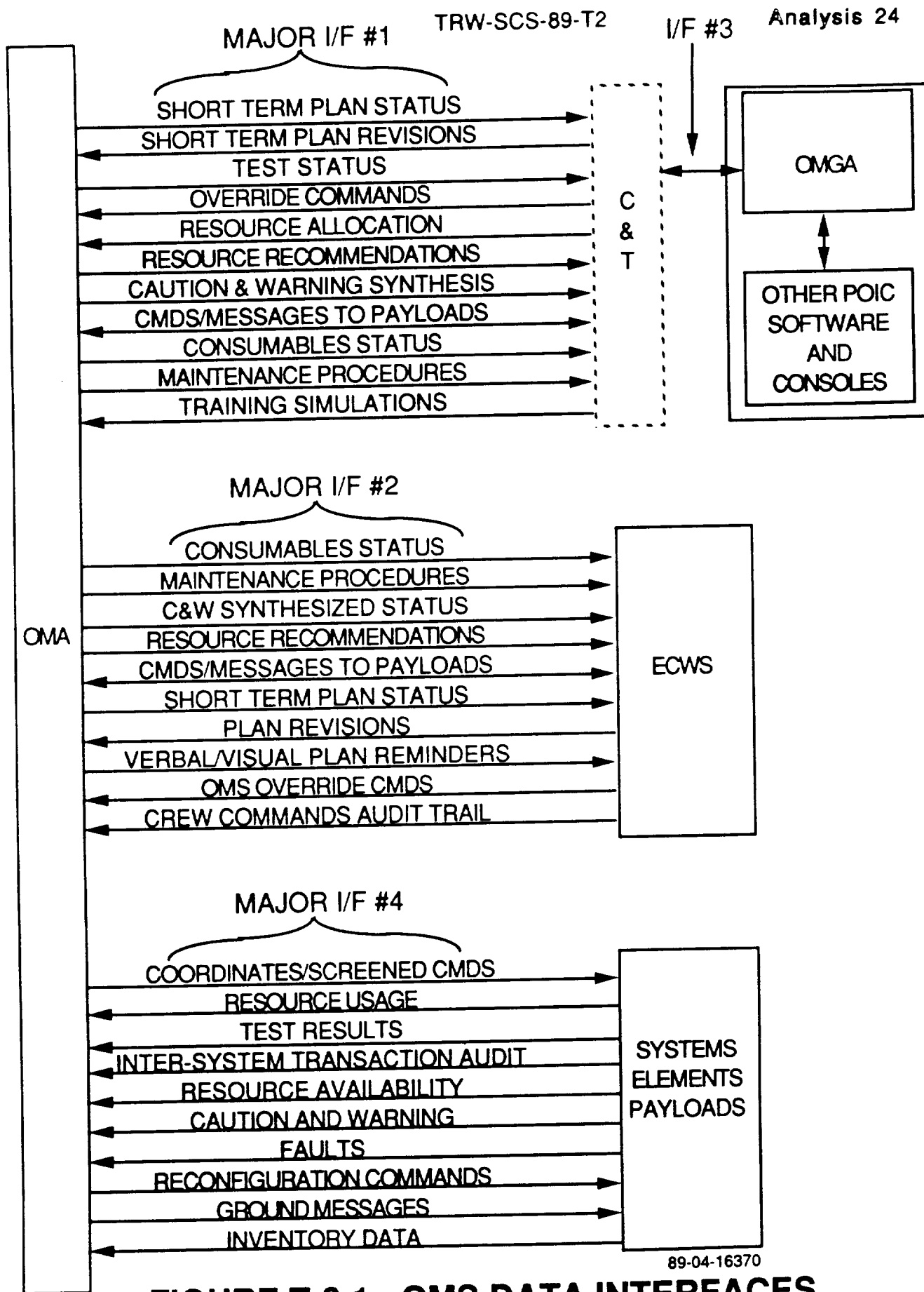
### Development

1. Greater effort will be necessary to develop, integrate, and interface system simulations with the DMS kits, due to the additional data flow required by OMS functionality (see #2 above). This is seen as a one-time requirement which should not affect the SCS development configuration. Consideration should be given though, to the steady-state effort required to maintain these simulations as the SS evolves.

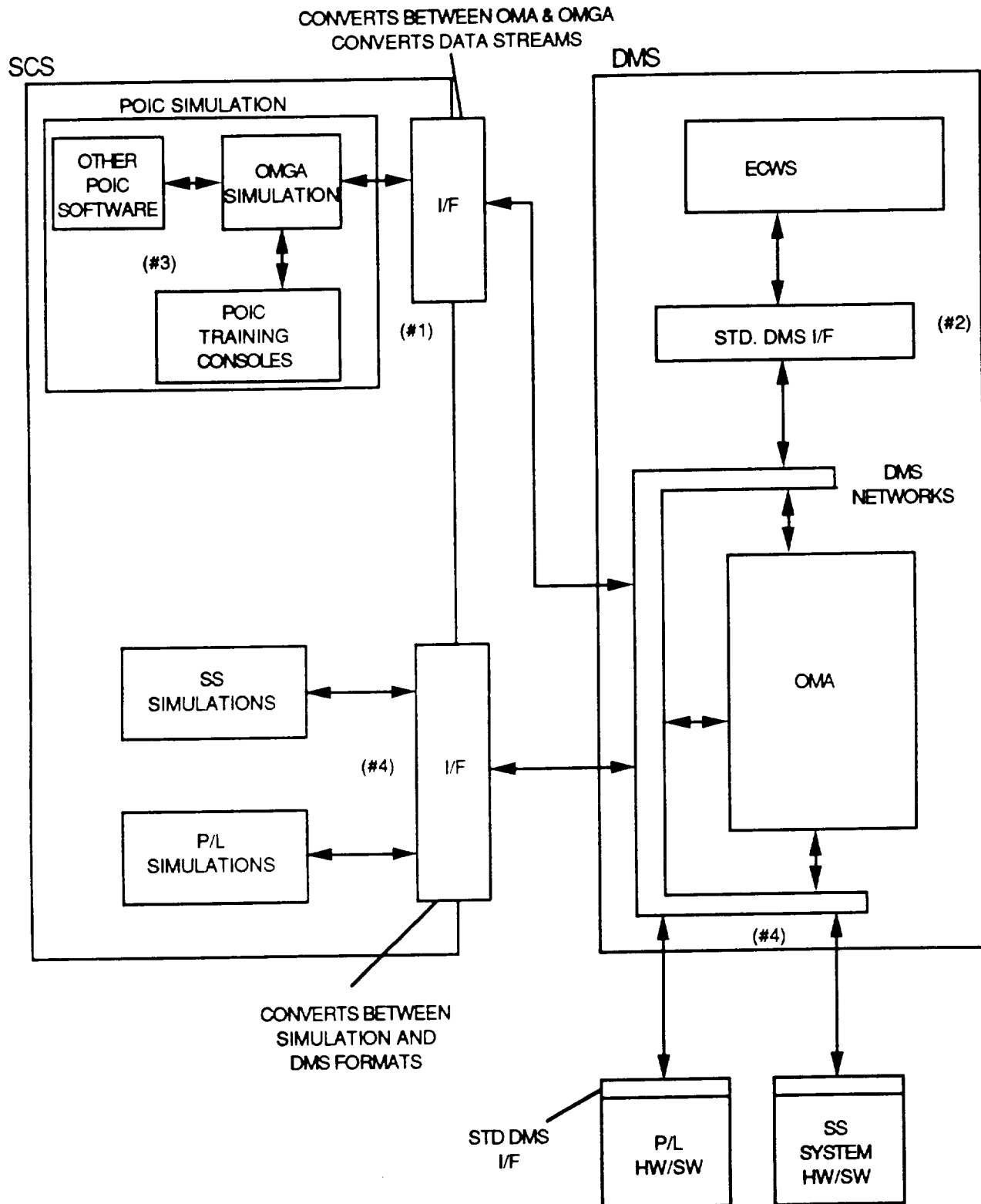
2. While additional effort must be made to develop the OMGA and its interfaces with the DMS kit and the other POIC functions, this is also seen as a one-time requirement which should not affect the SCS development configuration, though consideration should be given to the steady-state effort required to maintain these simulations as the OMS evolves, as well as the greater computational capacity required to execute the OMGA during development activities.

### Operations and Evaluation

1. As noted in SCS Issue No. T-3, since crew and ground procedures can be expected to be heavily oriented toward the use of payload OMA functions, a high fidelity simulation of these functions (or the use of actual OMA flight software) will be required to support procedure development and verification. Additionally, the testing of maintenance procedures on flight-equivalent hardware will require a high fidelity representation of the OMS maintenance management function. These requirements may be satisfied by the OMS functionality already described above for the Training and Development functions. No Operations Evaluation-unique OMS capabilities should be needed.



**FIGURE T-3.1 - OMS DATA INTERFACES**



89-04-16372

**FIGURE T-3.2 OMS IMPLEMENTATION AT PTC**

**Study Title: Scope of Integrated Core Subsystem Training in PTC****Study No. T-4      Report Version: 3**Problem

The load on the PTC simulation computer system due to subsystem simulations must be quantified in order to determine the maximum loading on the SCS at any given time to support payload training. Since the PTC has no responsibility for subsystem training, the load due to subsystem simulations will only be related to what is required to support payload operations training. Since payload simulators must be transportable to the SSTF to support integrated SS training it will be necessary for the payload simulators to interface with the SSTF subsystem simulators. Therefore there will be an SCS load due to payload/subsystem integration and in some cases subsystem simulators will have to run on the host SCS to support payload training.

Approach

The WP01 Trainer Development Plan will be reviewed to determine the current anticipated relationship between subsystem and payload simulators. Past experience with Spacelab subsystem simulators in the Spacelab Simulator at JSC will be utilized to determine potential SCS load.

Analysis Overview

The WP01 Trainer Development Plan indicates that simulated payload interface will be required for such US Lab subsystems as the Vacuum Vent System, Acceleration System, MPSG, Mass Energy Analysis (MEA), and the Process Material Management Subsystem. The WP01 Trainer Development Plan further indicates that no simulated payload interface is required for common subsystem simulations such as the Environmental Control Life Support System and the Thermal Control System. However Spacelab experience dictates that this might not be true. Hooks to simulate the payload load on the Environment Control System, Thermal Control, and Electrical Power Distribution might be required to provide adequate training on payload operations.

Inputs

1. D683-10135-1, WP01 Trainer Hardware/Software Development Control Plan, Draft 1, October 31, 1988.

Assumptions

4. A worst case load on the SCS is assumed for subsystem models which might be required to support payload training.

Analysis

The WP01 Trainer Development Plan defines US Laboratory software simulations requiring payload interface for the following subsystems:

- Vacuum Vent System \*
- Acceleration System \*
- MPSG (General Lab Support Facility) \*
- Laboratory Support Equipment
- Preservation and Storage System
- Maintenance Workstation/Lab Sciences Workbench \*
- Life Science Glovebox
- Mass Energy Analysis (MEA) Subsystem \*
- Equipment Washer/Sanitizer
- Process Materials Management Subsystem Simulation \*
- Inventory Management System (IMS) \*

While all of the above listed subsystems are defined as requiring software simulators with payload interfaces it appears that many of these systems are actually hardware systems that would not be particularly applicable to software simulation. Therefore, for the purpose of this study, only those subsystems from the above list marked with an asterisk are considered to present any load to the PTC SCS.

The WP01 Trainer Development Plan also lists the following common subsystem simulations.

- Water Recovery and Management System
- Waste Management
- Air Recovery
- ACS
- Temperature and Humidity Control
- Fire Detection and Suppression
- Fluid Flow Loops \*



Audio/Video \*

Electrical Power Distribution \*

Guidance Navigation and Control\*

Communications and Tracking\*

Even though the Trainer Control Plan does not identify any payload interface for most of the common subsystems listed above, our Spacelab experience indicates that there will be a payload interface for the subsystem simulators marked above with an asterisk.

From the above two lists a total of 12 subsystems have been identified that potentially will require software simulation on the PTC SCS in order to support payload operations training. Since the function of the PTC is only to provide payload training it is assumed that relatively simple low fidelity models is all that will be required for these subsystem simulations at the PTC. Subsystem training will be supported at the PTC only to the level necessary to operated the payload and details of the subsystems will not be required for subsystem simulators on the SCS. However, the interface between the payloads and these lower fidelity subsystem simulators will need to be the same as the interface to the higher fidelity subsystem simulators that will reside in the SSTF. This will be necessary to minimize modifications to the payload simulators when they are transported to the SSTF for the final phase of SS increment training.

The Spacelab Systems Simulator (SLS) at JSC provides some experience for anticipated subsystem simulations that might be required for the SS. The SLS has operated using two Perkin and Elmer 832 computer systems. The SLS has provided simulations for the Environment Control System, the Thermal Control System, the Electrical Power Distribution System, the Subsystem Computer Operating System (SCOS), and Igloo systems. Each of these simulations has consisted of from one to eight models. Execution rates for the various models vary from 1 to 25 Hertz. The payload interface load to these subsystems has not been dynamically simulated but the capability has been provided for the simulation director to manually input payload load parameters for such subsystem simulators as the Thermal and Electrical systems.

For the purpose of this study we will assume that a subsystem simulator will be a simple model that will be equivalent in size to a simple payload simulator. Using the estimated size requirements from the Spacelab experience (see Study T-1) provides the following requirements for the subsystem simulation load on the SCS.

	Lines of Code	Memory Requirements (K bytes)
12 simple models @7150	= 85,800	@116 = 1,392
	-----	-----
Total Subsystem Load	85,800	1,392
per Consolidated		
Configuration		

If we make the same assumption relative to part task trainers for subsystem requirements that was applied to the payload SCS load we would again assume that each part task trainer will require one third the load of a full increment. Using these estimates and the training flow requirements that were shown in Figure T-1.1 in study T-1 (one full consolidated configuration, one combined payload configuration, 3 different part task trainers, and 1 POIC configuration) provides a total SCS training load requirement for subsystem simulators as follows:

	Lines of Code	Memory Requirements (K bytes)
1 Consolidated Configuration	@ 85,800 = 85,800	@ 1392 = 1,392
1 Combined Payload Configuration	@85,800 = 85,800	@ 1392 = 1,392
3 Part Task	@28,600 = 85,800	@ 464 = 1,392
1 POIC Configuration	@ 85,800 = 85,800	@ 1392 = 1,392
Total Subsystem SCS Load	----- 343,200	----- 5,568

### Results

1. The SCS shall support payload/subsystem interfaces for the simultaneous execution of 6 independent training systems (1 full consolidated increment trainer, 1 combined payload trainer configuration, 3 part task trainers, and 1 POIC configuration).
2. The subsystem simulation load on the SCS for a full increment trainer can be assumed to consist of 12 simulators containing a total of 85,800 lines of codes and requiring 1,392 K bytes of memory.
3. A part task trainer can be assumed to consist of 3 subsystem simulators containing a total of 28,600 lines of code and requiring 464 K bytes of memory.

### Open Issues/Notes

**Study Title: Fidelity of Element Control Workstation (ECWS)****Study No. T-10; Report Version 2**Problem

This study examines the system hardware requirements for representing the ECWS with varying fidelity. The implications of using the flight equivalent ECWS and an ECWS simulator are explored.

Approach

The approach for determining these requirements is to search through published reports, extract findings from various working groups, and hold discussions with users.

Analysis Overview

Requirements for the ECWS, like other SS systems, are not fully defined yet. However, careful study of published material and presentations, in conjunction with user discussions, has provided the information presented below. It must be noted that since requirements are not yet solidified, the ECWS description presented below only represents the information available at this time, and will likely be changed.

Inputs

1. SSP 30261, Rev. B Architectural Control Document, Data Management System DMS Baseline, J. N. Dashiell, Nov. 29, 1988
2. JII-2782-3913 November D&C Splinter Minutes
3. D683-10001-2-6 Boeing Proposal, pp 6-21 - 6-24

Assumptions

5. The SCS ECWS is not required to provide the nonpayload related functionality of the flight equivalent ECWS. However, the flight equivalent ECWS may be used for the SCS ECWS.

AnalysisECWS Purpose

The purpose of the ECWS is to provide the primary user interface, including command and control, for payloads.

ECWS Subsystems

The ECWS is composed of the following subsystems: video display and recording, audio distribution and recording, caution and warning (C&W) indicators, and multipurpose application console (MPAC). The ECWS is interfaced to the communications and tracking (C&T) system, the time distribution bus, the C&W system, the global and local Core Network, and the payload science network.

### Video Subsystem

The C&T system is responsible for providing video distribution to the ECWS. The video subsystem consists of a 19 inch color monitor, a high quality video cassette recorder, and a hand controller for camera control. The VCR has picture processing functions such as time display, picture within picture, freeze frame, slow motion, etc. It is remotely controllable from the ECWS MPAC. The video subsystem is discussed further in Study T-15, Requirements For PTC Payload Video Data.

### Audio Subsystem

The C&T system is responsible for providing audio distribution to the ECWS. The audio subsystem consists of a dual audio cassette recording system, and a communications interface to the C&T system. A communications panel for distributing audio sources is also provided.

### Caution and Warning Indicators

The ECWS provides indicators for the Caution and Warning (C&W) System. The C&W system also has the capability for a voice annunciation system.

### ECWS MPAC

The ECWS MPAC consists of a 32 bit workstation (like the IBM PS/2 Model 80) with display, keyboard, and a mass storage system with magnetic and optical disk. The MPAC will provide access to the DMS, including global and local Core networks, the payload science network, and the C&T system.

### ECWS Training Requirements

The ECWS simulator must in full fidelity mode have the same user interface characteristics as the flight system. The external interfaces; command and control, data acquisition, and network connections must be compatible with flight equivalent systems. A common and flexible user interface provided by the ECWS will simplify payload operations.

### ECWS Simulator Approach

When examining the ECWS from a payload operations training perspective, the question of requirements for modelling the nonpayload related portion of the ECWS arises. This includes the Caution & Warning (C&W) indicators, portions of the audio subsystem (perhaps), and large segments of ECWS software. The assumption is made that there is no requirement for modelling the nonpayload related functions of the ECWS. The options for the ECWS simulator include the following:

1. Use the flight equivalent ECWS and develop whatever additional capabilities are necessary to support simulator operations and payload training. The ECWS, for example, may be required to interface with SCS specific equipment in addition to the DMS kit. This approach requires early availability of the actual ECWS in time to support initial training.

2. Develop the ECWS simulator as part of the SCS. Implement only the functionality required to support payload operations training. There are two implementation approaches for the SCS developed ECWS simulator.

- A. Intelligent workstation with resident simulation model and associated subsystems.
- B. Terminal and ECWS subsystems controlled by a task on a central computer.

The ECWS simulator configurations identified above are discussed in greater detail below.

### Flight Equivalent ECWS Simulator

The flight equivalent ECWS would provide the highest fidelity simulation and should be used, if available. Software to support payload operations training will be required. The ECWS simulator software is further discussed in a later section.

### SCS Developed ECWS Simulator

If the flight equivalent ECWS is not available, the SCS will develop the ECWS simulator. There is a wide range of fidelities with which the ECWS can be simulated. These ranges of fidelities are discussed below. Only those functions that are related to payload operations training will be fully implemented according to the ECWS requirements.

### ECWS Simulator Requirements

From the ECWS description given above, the ECWS simulator requirements can be determined at a high level as constituent subsystems. The ECWS simulator will include the following at some level of fidelity.

- 1.Video subsystem.
- 2.Audio subsystem.
- 3.Caution and Warning indicators.
- 4.ECWS MPAC.
- 5.Connection to the DMS networks.
- 6.Support software to control the ECWS.
- 7.Command and control software to interface with payloads as a minimum and possibly with the SS Core systems.

In addition, the ECWS simulator will include functionality related to training and an interface to the Simulation Control System (SCS).

### Fidelity of ECWS Simulator

The ECWS simulator can be represented by a wide range of fidelities, regardless of whether or not the flight equivalent ECWS hardware is used. Representative fidelity ranges of low, medium, and high are studied and a range of implementation options are presented. Each of the requirements for the ECWS simulator described above are studied for these fidelity ranges. The ECWS simulator system performance is determined by combining the performance of its component subsystems.

#### Video Subsystem Fidelity

The video subsystem of the ECWS simulator is principally responsible for the display and storage of payload acquired video data. A range of fidelities for significant video subsystem parameters is shown in Table T10-1. The video subsystem may be implemented as either a separate set of hardware or simulated on a workstation from predefined images stored on disk.

#### Audio Subsystem Fidelity

The audio subsystem of the ECWS simulator enables communications to all areas of the SCS. A range of fidelities for significant audio subsystem parameters is shown in Table T10-2.

#### Caution and Warning Indicator Fidelity

A range of fidelities for Caution and Warning indicators is shown in Table T10-3.

Table T10-1 Video Subsystem

Parameter	Levels of Fidelity		
	High	Medium	Low
Resolution	2048X2048 (digital)  1280X1024 (digital)	525 line NTSC (standard video)  640X350	SSTV (low rate)  320X200
Screen size	25 inch	19 inch	13 inch
Video format	HDTV video (1125 line)	NTSC video (RS-170A) (525 line) EGA	CGA
Range of color	65,536 colors	256 colors NTSC video (RS-170A)	16 colors
Remote camera control	Full 2-axis control, zoom	fixed camera	no camera
Remote VCR control	Auto control for all functions	manual, front panel control	no VCR
Video switching	Auto switching for up to 8 video sources	Manual switching for up to 4 video sources	video from workstation display only
SCS computer resource impact	No impact if flt. ECWS used, except for sim. video	Significant HW/SW impact	low HW impact medium SW impact

**Table T10-2 Audio Subsystem**

Levels of Fidelity			
Parameter	High	Medium	Low
Communications	Full communications to all stations, PTC, std telephone system	Intercom to operators	No dedicated system
Audio recording	Dual cassette deck w/remote control, auto switching of audio sources	Manually operated tape deck, manual source switching	Mock-up of tape deck
Communications patch panel	Auto digital switching system	Manually operated patch panel	Mock-up of patch panel
SCS computer resource impact	No impact if flight ECWS used	low HW impact, no SW impact	Minor HW impact



**Table T10-3 Control and Warning Indicator Subsystem**

Parameter	Levels of Fidelity		
	High	Medium	Low
Controls and switches	Full implementation of all controls as on flight hardware	Implementation of payload related controls, other controls nonfunc.	Mock-up of controls-funct. impl. in software
Indicators	Full implementation of all indicators as on flight hardware	Implementation of payload related indicators, other controls nonfunc.	Mock-up of indicators-funct. impl. in software
SCS computer resource impact	No HW impact if flt. ECWS used, low SW impact	low HW and SW impact	minor HW impact, med. SW impact

**ECWS MPAC Fidelity**

The ECWS MPAC simulator provides the computation portion of the ECWS simulator. It is the primary means for controlling and monitoring the payloads in the SCS. A range of fidelities for the ECWS Multipurpose Application Console subsystem is shown in Table T10-4.

**ECWS Simulator Software Fidelity**

The ECWS simulator software must provide the functionality of the flight ECWS. It must be capable of being configured from the SCS. A range of fidelities for the ECWS simulator software is shown in Table T10-5.

**Analysis of ECWS Simulator Fidelity**

Three levels of ECWS simulator fidelity were described above, identified as high, medium, and low. A simplification of the alternatives presented is to characterize the high level of fidelity as the flight equivalent system, the medium level of fidelity as a SCS developed emulation of the ECWS, and the low level of fidelity as a partial implementation of the ECWS requirements. The medium fidelity SCS developed ECWS simulator is envisioned to be architecturally very similar to the flight equivalent ECWS. The low fidelity SCS developed ECWS simulator, however, has significant architectural differences from the flight equivalent system. This is due to the implementation of ECWS subsystems in software. Therefore, the low fidelity system

actually has greater processing requirements than the other two alternatives. From a SCS cost point of view, the flight equivalent ECWS simulator (high level of fidelity) is less expensive than the SCS developed ECWS simulator (medium level of fidelity) by a considerable margin. The limited functionality version of the ECWS simulator (low level of fidelity) is the least expensive of the three alternatives. As stated earlier, the use of the flight equivalent ECWS is the most desirable alternative.

Table T10-4 ECWS MPAC Subsystem

Parameter	Levels of Fidelity		
	High	Medium	Low
Processor	32-bit workstation, 3-4 MIPS, 8MB memory, multitasking OS	Implement simulator as a task on a 32- bit minicomputer, shared with other SCS functions	16-bit micro, 2MB memory, DOS
Display	19 inch color graphics monitor, 1024X1024 resolution	13 inch graphics terminal	13 inch EGA graphics monitor
User interface	Keyboard, light pen, touch sensitive panels	Keyboard, light pen	Keyboard, mouse
Network connection	Network interface, fiber optic network	RS 232 interface, 9600 baud	Network interface
Mass storage	300 MB magnetic disk, 2 - 6 GB optical removable disk drives	180 MB magnetic disk, 1 removable disk drive	40 MB disk drive, floppy drive
ECWS Subsystem interface	IEEE 488, RS 232	RS 232, discrete	no electrical connection
SCS computer resource impact	No HW impact if flt. ECWS used, medium SW impact	Medium HW and SW impact	Medium HW impact, Significant SW impact

**Table T10-5 ECWS Simulator Software**

<b>Parameter</b>	<b>Levels of Fidelity</b>		
	<b>High</b>	<b>Medium</b>	<b>Low</b>
Interface to ECWS subsystems	Flight equivalent software to control subsystem	SCS developed software to control subsystem	Implement the effect of subsystem in software
Interface to SS Core systems	Flight equivalent software, full functionality	Limited interface to Core systems	Only those I/F reqd. for P/L operation
Interface to Payloads	Flight equivalent software, full functionality	SCS developed software, full functionality	Full payload control, lim. audio & video
Training support	Flight equivalent software, computer aided instruction, interface to SCS	SCS developed software, interface to SCS	
SCS computer resource impact	Medium SW impact to control simulation	Significant SW impact	Highest SW impact of the the 3 alt., med. HW impact

### Results

1. The ECWS MPAC will be the primary user interface to the payload for the SCS.
2. The ECWS will interface to the SCS executive application through the DMS.
3. The SCS executive application will be capable of configuring the ECWS.
4. There may exist some audio requirement for the SCS.
5. There may exist some Caution and Warning requirement. for the SCS
6. There may exist some Video Configuration Requirement for the SCS. See Study T-15.
7. The required fidelity of the ECWS is as follows:
  - a.) All displays and controls associated with the ECWS should have the same appearance and response characteristics as the flight system.
  - b.) The user interface to the DMS software for those functions required for payload training should have the same appearance and response characteristics as the flight system.

### Open Issues/Notes

1. The specific configuration of the ECWS is not clear. For example, will the C&W, audio, and video portions of the ECWS be supplied along with the ECWS?

**Study Title : Support for Interoperable (Remote Executions) Simulations****Study No. T-13; Report Version 2**Problem

The PTC requirement for support of remote operations could range from no remote operation capability of the PTC simulators to a full simulator control and trainee interfaces from remote locations such as PI sites.

Approach

The study will determine the requirements of the SCS to support interoperable simulations. The approach for determining these requirements is to search through published reports and conduct interviews with personnel currently working on training systems with similar purpose.

Analysis Overview

An examination of various remote site possibilities and their affects on the SCS design ( interfaces and distributed processing requirements) was performed.

InputsAssumptions

Training done via remote execution is either on the SCS remotely, or the trainees come to MSFC and train here. Thus, the computing load would be the same, and will be accounted for in the study.

Analysis

This study provides additional insight into the affects of remote operations capability on the SCS system design. The affects are determined by examining the various remote site possibilities that might be required in conjunction with the SCS.

The remote possibilities can be categorized into three groups. A discussion of each category is below.

1. Trainees at PTC and simulators at PI remote sites.
2. Trainees remotely trained at their local sites.
3. PI remotely developed software using SCS provided data.

Category 1. involves a trainee operating a PTT at the PTC. The trainee might find it useful to train using a PI's home site simulator. Two possibilities immediately arise from this scenario. First, an experiment would be performed at the local PI's site

and the results would be uploaded to the SCS for storage in a file or files. This data then could be reviewed at a later time by a trainee. Second, an instructor would initiate and guide the experiment from the PTC with the trainee (also at the PTC) responding to the generated results at a workstation.

The above situations are not practical and produce problems. In the first situation reviewing a set of results in many cases after the fact would not provide enough training to warrant the effort. In the second situation, the PI's simulator is offsite and the trainee would not have access to the C&D panel for hands-on training. As a result, only some payloads, in particularly those that do not require trainee hands-on responses, could be utilized for training in this manner. Since a full training capability is not practical, these possibilities are very poor candidates to be considered in the development of the requirements.

In category 2, training may be remote to the PTC. A remote training capability would make the PTC simulators and training capability more accessible to trainees by potentially providing training at their home sites. Training of this type should be limited up to and including the PTT level. Consolidated training would have to be performed at the PTC. The usefulness of this remote training technique will be limited unless the local workstation is a duplicate of the PTT workstations so that a DMS kit can be attached to the local workstation, or a DMS simulation utilized on the workstation. The DMS kit might provide the communication interface to the host of the PTC PTT's. An interface of this type creates a remote PTT, which would serve as one of the PTC PTTs. Thus reducing by one the number of PTTs at the PTC, but maintaining the total acceptable number of active PTTs in general. If the workstation local to the trainee is not a PTT duplicate, then a specialized DMS kit or DMS simulation will need to be developed in order to complete the interface. This could be a costly investment.

Category 3 does not involve training as was apparent in the other two categories. Instead it involves prototyping and development at a local PI site. For example, a PI desires to test prototype software he developed to execute on his hardware configuration using SCS supplied data. In this situation a data downlink to the local PI facility would prove to be a necessary feature. Irregardless, it is important to note that contrasting the capability to download data is the capability to upload data. In category 1 the capability to upload data results from a remote execution and is a necessity. However, in category 3 the capability to upload data could prove detrimental. Unless the constraints are very tight, uploading remotely developed software could bypass any configuration management scheme and thus damage any PTC baseline. Therefore, precautions should be taken to prevent any problems that could occur by uploading remotely developed software.

## Results

Allowing training on remote simulators from the PTC is not practical and can not be validated for all possible simulators. Therefore, the possibilities described in category 1 are poor candidates to be considered in the development of requirements.

Home site training is not practical if the local workstation is not a duplicate of a PTT, because specialized DMS kits or DMS simulations would need to be provided and this would be a costly investment.

## Candidate Requirements

The SCS shall provide a capability to interface with remote training. This training shall be restricted to home site training. Home site training have the following characteristics:

- Training shall be limited to the PTT level.
- The local workstation shall be counted in the total acceptable number of active PTTs.
- The local workstation shall be a duplicate of the PTT workstation.
- A DMS kit or DMS simulation shall be used with the local workstation as it would with a PTT at the PTC.

The phrase "capability to interface" includes any multitasking operation system or distributed computing system necessary.

The interfaces to remote execution sites shall provide the capability to download data from the PTC to the remote site and shall provide the capability to upload data from the remote execution site to the PTC.

## Open Issues/Notes



**Study Title: Requirements For PTC Payload Video Data****Study No. T-15**      Report Version 2Problem

Payload video data will be required for SCS training. The level of fidelity and the type of video data required need to be determined. Requirements for putting digitized video data into a data stream must be determined.

Approach

The study will determine the requirements of the SCS to support payload video data for training. The requirements are determined by searches of published reports, findings from various working groups, and discussions with users.

Analysis Overview

Video is used for SS payload operations to enable the SS crew and ground personnel to monitor experiments. The video data is recorded, providing a permanent visual record of the experiment. The recorded video data can be subsequently analyzed, allowing greater understanding of the experiment. While many of the SS experiments are performed in one of the laboratory modules (USA, European, Japanese), experiments may be performed anywhere inside or outside the Space Station.

The video requirements for the SS are implemented by the video subsystem of the Communications & Tracking system. Video cameras are located strategically throughout the Space Station. These cameras are remotely controllable from various points within the SS including the ECWS. Also, external video sources such as teleconferencing and playback are supported by the video subsystem. The SS video data is distributed through a broadband network, similar to a CATV system.

Inputs

1. SSP 30260, Rev A Architectural Control Document, Communications and Tracking System
2. Msg 0JII-2782-2913 November D&C Splinter Minutes

Assumptions

6. The SCS video system will be compatible with the video subsystem of the SS Communications and Tracking system.
7. The SCS video system will be capable of interfacing to the SSIS network.
8. The SCS video system, while compatible with the SS video subsystem, is not required to provide 100% of the functionality of the SS video subsystem.

9. SCS video data is not required to be digitized and sent through the C&T system to the POIC.

### Analysis

#### Video Requirements For Training

The video requirements for training in the SCS at a high level are as follows:

1. Familiarize crew and ground personnel with video system operation relative to payloads.

2. Monitoring and recording of experiments.

3. A realistic visualization of payload and experiment progress where flight payload or mock-up is not available.

Video data from the SCS will not be digitized and transmitted to the POIC through the C&T system. However, if it is determined that payload video is critical to POIC operation, video data may be distributed to the POIC through a CATV system. In addition, the POIC trainers in the SCS will have access to payload video data through the SCS video distribution system.

#### Video Sources For Payload Training

The following are potential video sources for payload training.

1. Video camera.

2. Playback from video recorder.

3. Video images, still or animated, from mass storage such as optical disk.

#### Payload Video Data

The payload video data, which drives each of the above video sources, may be generated in the following ways.

1. Video camera monitoring the flight or simulated payload.

2. Video camera monitoring photograph of payload.

3. Computer generated scene. These scenes may be still or animated. Computer generated video data is discussed further below.

The specific requirements for payload video data will be determined for each experiment. For some experiments, video data is of minor importance for training. For

these experiments, static video images may be displayed or none at all. For other experiments, dynamic video data may be critical to crew training.

In some instances video data may be important for training but not available from the payload. In this case the video data may be simulated through animation techniques. The animation need only show those portions of the experiment in detail that are of prime importance.

### Computer Generated Video Data

Computer generated video data can provide a wide range of functionality. At the low performance end of the spectrum, static images may be displayed which show only the minimum level of detail required for training. At the high performance end of the spectrum, graphics engines may be deployed to generate high resolution images with realistic motion in 3D using solid modelling techniques. The emerging digital video interactive (DVI) technology may also be appropriate. Using DVI, sequences of video images with full motion and audio are displayed under computer control. Different segments are displayed depending on user selection. A representative selection of computer generated video parameters at three fidelity levels is shown in Table T15-1.

### Video Data Acquisition and Storage

The video data may be acquired in High Definition TV (HDTV) or NTSC format and stored on analog tape or converted to digital and stored on mass storage. The storage of video data on analog tape is a mature technology and does not present special requirements. However, due to the high bandwidth of digital video data, special techniques and technologies are required for the storage of digital video data. The bandwidth and digital storage requirements for a NTSC video signal is shown in Table T15-2. The significant use of digital video will require special processing hardware for data compression and a large storage capacity, likely implemented on an optical disk.

### Video Subsystem Parameters

The significant video subsystem parameters are shown at three different fidelity levels in Table T15-3.

Table T15-1 Computer Generated Video

Parameter	Levels of Fidelity		
	High	Medium	Low
Image resolution	1280X1024	640X480 (VGA)	640X350 (EGA)
Image representation	Solid modelling, multiple light sources	3D wireframe	2D
Frame rate	30 frames/sec	2 frames/sec	static
Graphics source	Video frame buffer, scanned image, CAD sys.	Scanned image, CAD system	CAD system
Display control	Pan, zoom,	Pan, zoom, freeze	Pan, zoom
SCS computer resource impact	Significant HW and SW impact	Medium HW and SW impact	Low HW and SW impact

**Table T15-2 Digital Video Bandwidth and Storage Requirements**

<b>Video Signal</b>	<b>Bandwidth</b>	<b>Storage</b>
NTSC video signal	6 MHz	Analog video tape
Uncompressed color video, 512X680 res., 30 frames/sec	167 M bit/sec	20.9 M byte/sec
Simple compression techniques, 512X680 res., 30 frames/sec	6 M bit/sec	750 K byte/sec
DVI compressed color video, 100:1 compression, 512X680 res., 30 frames/sec	1.67 M bit/sec	209 K byte/sec

**Table T15-3 Video Subsystem**

Parameter	Levels of Fidelity		
	High	Medium	Low
Resolution	2048X2048 (digital)  1280X1024 (digital)	525 line NTSC (standard video)  640X350	SSTV (low rate)  320X200
Screen size	25 inch	19 inch	13 inch
Video format	HDTV video (1125 line)	NTSC video (RS-170A) (525 line) EGA	CGA
Range of color	65,536 colors	256 colors NTSC video (RS-170A)	16 colors
Remote camera control	Full 2-axis control, zoom	fixed camera	no camera
Remote VCR control	Auto control for all functions	manual, front panel control	no VCR
Video switching	Auto switching for up to 8 video sources	Manual switching for up to 4 video sources	video from workstation display only
SCS computer resource impact	No impact if flt. ECWS used, except for sim. video	Significant HW/SW impact	low HW impact medium SW impact

## Results

The above analysis presented a wide range of fidelity options for the SCS video system. The level of fidelity selected will depend on SS video system fidelity, SCS training requirements, and funding considerations. Also, the requirements for training video will vary from payload to payload. The SCS will support the development of video for payload training from the resources at its disposal. The following candidate requirements are presented:

1. The SCS video system will be compatible with the video subsystem of the SS Communications and Tracking system.
2. The SCS video system will be capable of interfacing to the SSIS network.
3. SCS video data will be in a RS-170A (NTSC) format, and in color.
4. The element, module, and attached payload trainers will support one video channel.
5. The video system will support video data from the following: video camera, video recorder, external video source, and from a workstation based DVI source.
6. The SCS will provide the capability to develop and display still and animated video images for training. The video images will contain sufficient detail to accomplish training. The computer based video will incorporate digital video interactive (DVI) technology. The DVI workstation will provide for the storage of the training video sequences.
7. The video camera position will be controllable from a 3-axis hand controller and an external computer.
8. The video system will have a video recorder which is controllable from an external computer and from front panel controls.
9. The video system display will be a NTSC compatible color monitor with a screen size of at least 19 inches.
10. The video system will be capable of switching any of the supported video sources to the display from a front panel control or from an external computer.
11. The video system will distribute video data to the operator consoles, instructor stations, and to the POIC trainers.

## Open Issues/Notes

**Study Title: Onboard Training****Study No. T-20 Report Version 2**Problem

Onboard training may be required to make the Space Station payload operations successful. The long flight times may require refresher training for the onboard crew on payloads not operated in recent months. Also, the crew onboard may have a payload arrive with the next increment which they have not trained on (due to the payloads late development), or which has changed to such a large extent, that the training they received before launch is no longer correct.

Approach

Experience with training on other systems will be reviewed, and, if possible, other training experts and/or flight crew will be contacted to discuss and resolve this issue.

Analysis Overview

Review and consideration of the SCS team's combined training experience was utilized to evaluate the various possibilities for onboard training. This resulted in several candidate ways in which onboard training could be conducted. We attended an Ed Gibson briefing in which he related the lessons learned on Skylab to Space Station. We also had the good fortune to be able to discuss these in a JSC/MSFC coordination meeting with Claude Nicollier (Spacelab 1 flight crew) and Chuck Lewis. This discussion reinforced our basic conclusions.

Inputs

1. Briefing by Chuck Lewis to SS Training Working Group, February, 1989.
2. Briefing by Ed Gibson, Skylab III astronaut, 7 March, 1989.

AssumptionsAnalysis

Our initial analysis, based on a considerable amount of training and systems experience, told us that onboard training could be done using 1) books, CBT, and audio/video onboard, 2) On-the-job training (OJT) with actual payload hardware/software, 3) an onboard simulation using some type of onboard simulator, or 4) onboard training, with the simulator on the ground, run through the C&T system. From this look at methods, we decided the best approach to selecting a method was to consider what problems could be solved using onboard training, i.e. what would be the principle purposes or uses of onboard training.



From the systems view point, onboard training would be for emergency situations that are not faced often, but for which the correct response must be fast and correct the first time (e.g. onboard fire, rapid decompression, power failure). Onboard training would also be used for critical tasks which the crew gets rusty at if training was too far in the past, and the task itself has not been performed for a while (e.g., reentering in the Apollo Command Module after it was docked to Skylab for 3 months, or flying the Shuttle through reentry after it has been docked for weeks or months to the Space Station). This was gleaned from flight crew talks and discussions.

For payloads, both to refresh on a payload not run for a while, and to train for a payload launched in a significantly different configuration than that used in training are the valid reasons for onboard training. If a payload is present onboard, and the crew are reasonably familiar with it, if there is a training problem, it would most likely be resolved with on-the-job training (OJT) using the real payload, and not a simulation. More than likely, the PI would be on a communications link to the onboard crew to serve as the trainer and helper utilizing audio, and a video link if necessary.

Given the above training purposes and use of OJT, it follows that onboard payload training would consist of using manuals, PC based simulations, or video and audio tape/disk training aids. All these would easily and efficiently serve to allow the onboard crew to refresh themselves on payload operations, or to prepare to operate a payload which had changed significantly since they trained on it. Also, a factor in not requiring a full up onboard payload simulation capability is that the 4 new arriving crew could readily aid in training the already onboard crew on a payload that had changed significantly, since the 4 new crew's training would be much more current than the 4 they were joining.

### Results

A full up onboard payload simulator/simulation capability does not appear to be needed for payload training. Training for emergency situations caused by payload malfunctions would seem to fall within the systems emergency umbrella that is JSC's responsibility.

### Candidate Requirement

The SCS manuals, PC based simulations, and video/audio tapes and disks shall be designed to be easily portable to and usable onboard the SSF for training purposes.

### Open Issues/Notes

**Study Title : Techniques for Supporting Late Changes to Simulators****Study No. A-3      Report Version 2****Problem**

How close to launch are changes allowed in the simulators, and what are the allowable magnitudes of the late changes. Small changes made too late in the cycle can have very adverse affects on not only the changed experiment, but other SCS support simulation activities.

**Approach**

The study will focus on state-of-the-art simulation development, emphasizing proven techniques and tools that could be incorporated into the SCS. To accomplish this study, reviews of current literature on state-of-the-art techniques and tools will be made and discussions with experienced simulator developers will be held to acquire a working knowledge of successful experience.

**Analysis Overview**

The two fundamental parts of simulators, hardware and software, are evaluated from the standpoint of state-of-the-art techniques and tools that can decrease the negative impact of late changes to SCS simulators. The techniques include modular programming and flexibility scenarios, and the tools include CASE and automatic programming.

**Inputs**

1. Case Tools For PCTC, Dave Scott, New Technology, Inc., Oct. 13, 1988.
2. Reducing PCTC Software Development Time
3. OP14 Plan Draft 1 D683-10135-1

**Assumptions**

10. Late changes to the simulators are a problem that the PTC/SCS people have to solve.

**Analysis**

To accomplish this study, reviews were made of current literature on state-of-the-art software engineering techniques that take full advantage of the constructs provided in the Ada programming language, and discussions with experienced simulator developers that have a working knowledge of successful hardware and software configurations.

The SCS simulations can be categorized into three basic classes :

1. Flight equivalent hardware and flight software simulations
2. Software simulation models
3. Hybrid simulations: software and/or equivalent flight hardware / software

Although all three classes will play some significant role in training exercises, it is estimated that (80 % to 90 %) of the payloads simulated are expected to be done via software simulations. Therefore, a more significant portion of this study was given to class 2 than was given to either of the other two classes. However, to facilitate continuity within the study, the discussion begins with class 1.

### Flight Equivalent Hardware and Software

One aspect that plays an important role in payload simulation is the use of hardware simulations. Since it will be impossible to use a full complement of actual flight hardware, flight equivalent hardware could be incorporated when available. By using flight equivalent hardware three basic situations develop affecting the composition of the simulations. These are (1) more flight equivalent hardware than flight software, (2) approximately an equal amount of flight hardware and flight software, and (3) a lesser amount of flight hardware than flight software. In all three situations the software aspect will be similar to the class 2 aspect. Therefore, any emphasis of software is postponed and will be incorporated in the discussion of class 2. Thus, emphasis will be placed on hardware and hardware simulations.

A change to a hardware simulator can have a definite impact on a training schedule depending on when the change occurred. If the change occurred on a particular simulator prior to training, then a change would have no real impact on the training schedule. However, if a change occurred on a particular simulator during training or after training completion, then definite problems would arise. One feasible approach that may be taken to offset the problem of a change during training is to modularize the hardware configuration to such a degree that maintenance and integration can proceed without impacting current operations. The trainer could shift emphasis to another aspect of payload simulation until the change is complete. In the situation where training is complete, the damage has already been done and retraining will have to be scheduled. However, the modular approach to hardware configuration could soften the training delay by having the simulator up and running with minimum impact or by allowing part of the simulator to continue to operate independently of the part that is changing.

### Software Simulation Models

Spacelab experience indicates that 80 % to 90 % of payload simulations will be implemented using software. Whether this software is flight equivalent software or simulation models makes little difference to the discussion of late changes. Consideration must be paid as to how software can be developed to buffer the side effects of late changes. The most obvious place to consider software change techniques is in the original development process itself. Since Ada is the SSE programming language, any software development techniques used to develop

simulation software should be chosen to take full advantage of the Ada software engineering constructs. One such technique is object-oriented programming. It is documented that Ada and object-oriented programming are well suited for each other.

Object-oriented programming is a modular design concept. The problem space is studied and decomposed into distinct objects. Each object contains both a description of the data types composing the object and all actions that can be taken on the object or by the object. By decomposing the problem into a series of distinct objects, the impact of late changes can be restricted to one module (object) or a group of modules (objects) and not scattered throughout the code. This capability would decrease the seek time (the time required to locate the position within the code that needs modification or enhancement) and decrease the potential of the problem of not locating all code change positions.

Another technique impacting software modification is growth and flexibility scenarios. This technique involves very close scrutiny of the system design and performing system design walk-throughs in order to determine major and minor impact points within the system design. If-then scenarios are investigated during the system design phase. Detailed documentation of the results of the scenarios can be used at a later time as a tool to evaluate the total impact of any late change to the overall system operation.

CASE tools have come to the forefront in software development in the past few years and they have been used in a productive manner to develop software. Automatic programming (AP) is another software development tool that has received a lot of attention in recent years. AP is not currently to a state of development that it can be of great benefit in the generation of simulation software; however, if research continues at the current pace, it may hold real possibilities for software generation in the future. A combination CASE tool and AP that permits a user to make requirements modifications and then automatically generates those changes into baseline code would be beneficial by potentially providing a minimum impact to training.

Hardware substitutions must also be considered for their impact to the software. These changes can be classified in two categories:

1. Software to hardware changes
2. Hardware to software changes

Software to hardware changes can be accomplished in a less traumatizing manner by using a software modularity approach. If the software has been designed using a modular technique, then any software simulated hardware configuration should be able to be replaced by the actual hardware or its equivalent with minimum impact.

Hardware to software changes may not occur often, but if it should occur, then the modular approach to system design will be of assistance in this situation as well. Assuming that the simulator system design was modular, then any hardware configuration should be replaced with a newly developed software module or reusable software module with minimum impact up to the interface and protocol features.

### Hybrid Simulations

Hybrid simulations consist of a combination of flight equivalent payload hardware and/or software and software simulation models. The degree of the combination will vary from payload to payload, but this situation does not initiate any new problems. Since hybrid simulations are composed of both flight equivalent payload hardware and/or software and software simulation models, the previous discussions are valid in this situation as well. If both hardware and software designs adhere to strict modular design techniques, then any experiment training feature that can not be implemented in hardware can be simulated in a software model with minimum impact.

It has been suggested above that late changes can be managed if significant forethought is provided early in the simulator design phase. But, once a late change has been determined, who decides the time needed to integrate and test the change and the immediate impact of such a change on the training schedule. One technique that has demonstrated promise in this area is a review board technique. A review board should consist of no less than one SCS system engineer, a PTC/SCS trainer, and the hardware and/or software designer. No change would be implemented without the consent of this board.

Throughout the discourse of this study, references have been made to minimum impact. To conclude this study, definitions are offered to clarify these references.

**Minimum Impact** - A minimum impact results from any change to the simulator that has no detrimental effect on the training schedule, i.e. the training schedule can be maintained without delay.

**Minor Change** - A minor change is any change that causes a minimum impact on the training schedule.

### Results

1. The SCS simulators shall be designed using state-of-the-art modular hardware and software design techniques. Modular means dividing and subdividing the design into distinct working modules.
2. The SCS shall be capable of incorporating a minor software change into an SCS simulator. The time required shall be determined by a review board. Incorporate includes requirements, design, code, test, integrate, maintenance, and documentation. Minor change is any change that does not cause a delay in the training schedule.
3. The SCS shall be capable of incorporating a minor hardware change into an SCS simulator. The time required shall be determined by a review board. Incorporate includes interface and test. Minor change is any change that does not cause a delay in the training schedule.

4. No late change shall be incorporated into the SCS simulators without an evaluation of the impact to the training schedule. "Evaluation of the impact" includes an estimated down time and an estimated training delay time.
5. The SCS shall incorporate state-of-the-art software development tools to be used whenever feasible in simulation software development.

Open Issues/Notes

**Study Title: Requirements For Integrating Flight Equivalent Payloads****Study No. A-5/A-14      Report Version 2**Problem

Enough must be known about the details of what will be required of the SCS to support flight equivalent payload hardware and software to allow the proper requirements to be written. The types of Ground Support Equipment (GSE) services needed must also be determined to decide what impact these have on the SCS.

Approach

The study will determine the requirements of the SCS to support use of payload flight hardware and the requirements for GSE-Provided services. The approach for determining these requirements is to search through published reports, extract findings from various working groups, and hold discussions with users.

Analysis Overview

The current requirements baseline is that SCS is required to support the use of flight hardware, both payload and nonpayload. The implications of using flight hardware in the SCS is examined. Categories of GSE-Provided services are enumerated and analyzed.

Inputs

1. D683-10135-1OP14 Plan, Trainer Hardware/Software Development Control Plan
2. SSP 30261 Architectural Control Document, Data Management System
3. DMS Baseline, J. N. Dashiell, Nov. 29, 1988

AssumptionsAnalysis

This study investigates the potential impact on the SCS architecture of using flight equivalent hardware for representing core SS systems and payload experiments. The impact on the SCS is analyzed by examining how the actual hardware package would interface with the other functional components comprising the SCS, and whether these interfaces would affect computing resource requirements.

The SCS is a simulation computer system concerned with the simulation of payloads for the Space Station. The simulations of SS core functions is the responsibility of the SSTF. The simulation of SS core functions which is required by the SCS in order to accomplish payload simulation will be performed by flight equivalent hardware or SSTF-developed simulators. A DMS kit is to be provided by

the JSC/WP02 contractor which will allow SCS access to standard SS software services such as Operations Management Application (OMA) and the Network Operating System (NOS). The DMS kit will provide the hardware required to interface payloads to the DMS and will include the Element Control Workstation (ECWS), MPAC(s), FDDI and other required networks, standard data processors (SDPs), network interface units (NIUs), multiplexer-demultiplexer (MDM), mass storage unit (MSU), time generation system (TGS), and bus interface adaptor (BIA).

The use of flight equivalent payload hardware and software offers full fidelity representations with a minimum requirement for simulation software to drive and process SS core and payload events dynamically. Because some systems, such as experiment payloads, may not be available within the time frame of SCS training, any solution should isolate the functional components of the SCS so that real payloads and payload simulation modules can be interchanged with a minimum impact. Other considerations, such as a requirement for onboard Space Station training, may require that both flight equivalent payload hardware and a software simulation model be developed and implemented in the SCS.

For this reason, the payload simulation, whether comprised of the flight equivalent hardware or a software model, should interface from application to application through the payload network. By interfacing the payload simulation in this manner, the details of the simulation are transparent to the rest of the system.

A top level SS DMS architecture is shown in Figure A-5.1. According to this figure, the payload instruments are attached to the payload FDDI network in one of three ways; direct attachment to the payload network through a NIU card set, connection to a 1553 link to a SDP, which is connected to the payload network, and connection to a MDM, connected to a SDP, which is connected to the payload network.

The SCS will be required to support software simulation models and simulations which incorporate flight equivalent payload hardware and software. Payload simulations which are completely software based will not be interfaced to a SDP or MDM. These simulation models will be architecturally similar to case where the payload instruments are interfaced to the payload network through a network interface unit. If the actual payload is interfaced to a SDP or MDM, these functions will have to be simulated in software to obtain a high fidelity simulation.

When flight equivalent payloads are used, the payload hardware must be stimulated by some means so that the experiment environment is simulated to the payload hardware. The specific method by which the environment is simulated will vary depending on the experiment. The SCS must be capable of providing a variety of payload stimuli in the representation required by the payload experiment. The payload stimuli will be controlled by the SCS. In this manner the SCS will control the experiment profile and be capable of introducing some anomalies into the experiment.





The SCS should require a minimum of SCS specific hardware resources such as dedicated networks, workstations, processors, etc. As a design goal, the SCS should control payload experiment simulation through the payload network from the user interface facilities of the ECWS or MPAC. The SCS executive may be able to utilize a dedicated standard data processor. Unless dedicated networks, workstations, and processors are used, the SCS will place an added load on the payload network and DMS resources beyond that required for SS operation. However, it is expected that these resources will be able to handle the additional load, especially since the SCS will probably not be required to model all experiments simultaneously.

In some cases the experiment may require resources such as fluids, gases, materials, etc. for proper experiment operation. Required facility services include electrical power, heating, cooling, gas and fluid transport system, and the building itself. Some US lab subsystems will also be required to interface to the SCS. These subsystems include:

Vacuum Vent System  
Acceleration System  
General Lab Support Facility  
Preservation and Storage System  
Maintenance Workstation/Lab Sciences Workbench  
Mass Energy Analysis (MEA) Subsystem  
Process Materials Management Subsystem (PMMS)

These special facility services will be GSE. It is expected that any experiment simulation at less than full fidelity will not require experiment-specific GSE services. Where GSE services are required, they may or may not be directly controlled from the SCS.

## Results

The above analysis leads to the following candidate requirements:

1. The DMS kit shall be provided by the JSC/WP02 contractor. The DMS kit shall allow access to standard SS software services. The DMS kit will provide the hardware required to interface payloads to the DMS and will include the ECWS, MPACs, networks, SDPs, NIUs, MDMs, MSU, TGS, and BIAs.
2. The SCS shall be capable of providing payload simulations through software models, hardware models, flight equivalent payloads, and combinations of hardware and software.
3. The SCS shall be capable of interfacing to the DMS applications and payloads through the application level services of the network operating system.
4. The SCS shall be capable of generating signals and presenting them to the payload hardware, MDM, or the SDP in the representation required by them for experiment stimulation.

5. At the hardware level, the SCS shall interface to the DMS and SS core services through the standard interface buffer (SIB) provided by the DMS.

**Study Title: Potential For SCS Expansion and Upgrade****Study No. A-6/A-8      Report Version 2****Problem**

This study looks at the development trends of major computing resources that will be required by SCS, and their effect on SCS and the SCS requirements.. The study is motivated by two SCS study issues: Issue A-8, Sizing Growth Potential in Capability/Capacity; and Issue A-6 Flexibility for Allowing Advanced Technology Insertion.

**Approach**

Current and projected technology is surveyed. The projections in this study are based on current technical literature and vendor briefings.

**Analysis Overview**

The formulation of a durable SCS architecture must take into account how forthcoming technology developments could promote changes to the initial SCS configuration. The objective of the present study is to survey the expected opportunities for enhancing SCS system hardware and software with emerging technology. It also considers the architectural consequences for SCS of being able to replace or expand original system hardware and software with new components.

To focus on appropriate computing resources, the basic hardware and software requirements of a preliminary SCS system conceptualization were derived. The SCS requirement was segmented into five categories of computing resources which could be divided further into alternative types. The categories are: 1) CPU platforms, 2) mass storage subsystems, 3) video subsystems, 4) communications subsystems, and 5) system interfaces.

In the following sections, computing resources have been characterized on a few select performance variables. These estimates of current and future performance reflect what can be expected from the average top-end products of each type.

**Inputs****Assumptions****Analysis****CPU Platforms**

Recent years have seen a broadening range of different computer types which today includes classifications such as mini-supercomputer, super- minicomputer, and super-microcomputer. These types join the traditional ranks of supercomputer, mainframe, minicomputer, and microcomputer. The SCS may have needs for a variety

of different computer types, and the range of alternatives for purposes of the present comparison will rely on the traditional four- category classification by subsuming their recent spin-offs. Thus, categories reflect the relative size of typical system configurations, although supercomputer refers to any computer using vectorization and parallel processing.

The current and anticipated performance of computer platforms suitable for SCS application is charted for the next ten years or so in Table A6/A8-1 through Table A6/A8-4. Where available, data are used to express the approximate speed, capacity, and flexibility of CPU platforms projected in each category. While speed and capacity refer directly to data processing power, flexibility refers to system features such as compatibility with standards, modularity, and reconfigurability. Where possible, cost is related to units of performance.

Overall, the tables indicate: 1) a convergence of platform capabilities, and 2) falling cost-to-performance ratios. The convergence appears to be predicated, in part, on an approach toward hard limits of microcircuit density and cycle speed for all CPU and RAM chips. On the other hand, the issue of flexibility in terms of being able to integrate different classes of computers in the same system, and possibly reconfigure the system down the road, seems to warrant primary consideration in formulating the SCS architecture. Indeed, emerging computer system architectures that emphasize cooperative distributed processing may depend heavily on this flexibility.

A related trend in systems development is the accelerating move to customizable CPU's and logic devices with the advent of microcodable processors, ASICs, PALs, and rapid VLSI implementation. While this study does not directly examine specialized processors, except for vector or array processors that might be embedded in supercomputers, it is assumed that the implementation of these devices into computing platforms is crucial to realizing the projections contained in this study.

In addition to both scalar and vector processing, graphics, data base, and logical inference processing are all moving toward more pipelined and parallel architectures. Along with the adoption of RISC techniques, parallelism is expected by 1995 to have a significant impact on the processing power of computers and specialized co-processors that are available. The more distributed the SCS architecture, the more the SCS implementation should be able to capitalize on these kinds of developments. One specialized example expected within the next year is the Parallel Inference Machine (PIM) which is a proprietary "engine" capable of providing real time rule-based processing on the order of 100,000 logical inferences per second (lips).

### Speed, CPU Platforms

Table A6/A8-1 presents typical instruction execution rates in terms of million instructions per second (MIPS) for different classes of computers and projects future trends. While MIPS have been used to characterize processing speed, this is only a very rough basis of comparison among different platforms. The nature of the platform's CPU architecture can significantly alter the relative weight of these generalized measures. The following factors, for example, will determine how these measures

translate into actual computing performance: processor type(s); instruction set; memory management; I/O control; memory size and access speed; code vectorization, branching, and optimization; multitasking; and multiprocessor topology. Some benchmarks (not provided) such as the Linpack set for vector processing and the Dhrystone set for scalar and system-oriented processing overcome some of these variables.

Simulator systems such as SCS and real time systems in general often demonstrate a sensitivity to context switching. Context switch and interrupt service performance can be quite critical for real time, synchronized, and multitasking/multiprocessing operations. This sensitivity, if not adequately handled by the computer architecture, can prevent the system from achieving the speeds indicated in Table A6/A8-1. This problem certainly affects system performance. However, it is resolved with the use of a real time operating system and is not normally of concern at the application level.

**Table A6/A8-1 MIPS Trend**

	1988	1990	1992	1995	1999
SUPER	2000	4000	12000	40000	500000
MAINFRAME	75	100	200	500	2000
MINI	10	20	50	100	500
MICRO	1	3	5	15	50

#### Capacity, CPU Platforms

Table A6/A8-2 presents typical memory configurations for different classes of computers and projects future trends.

#### Versatility, CPU Platforms

As alluded to earlier, the operating system used with the CPU platform can be of paramount concern for real time systems. The compatibility among operating systems across different CPU's within the system can also be of concern. While in the past, vendor computers have often been characterized by their proprietary operating system, the trend appears to be away from these exclusionary hardware/software configurations. The imminent switch to UNIX based operating systems by computer manufacturers such as IBM, DEC, and Cray is indicative of this trend. While UNIX is primarily intended for scientific applications, rapid prototyping, development, and

research, its hierarchical structure and support for the C language makes it amenable to specialized applications. The portability of the UNIX operating system also allows applications to be ported easily to different hardware platforms. An emerging standard, POSIX, is based on UNIX and promises to provide a common operating system across all the major hardware platforms in the near future. Table A6/A8-3 projects the trend for Operating Systems Standards across various classes of computers.

**Table A6/A8-2 RAM (MB) Trend**

	1988	1990	1992	1995	1999
SUPER	1000	4000	8000	16000	64000
MAINFRAME	512	512	1000	1500	2500
MINI	32	64	512	1000	2000
MICRO	1-4	2-8	8-12	16	32

**Table A6/A8-3 Operating Systems Standards Trend**

	1988	1990	1992	1995	1999
SUPER	[None	][UNIX,POSIX]			
MAINFRAME	[MVS/XA	][MVS/XB,POSIX]			
MINI	[UNIX V,VMS][UNIX,POSIX,PICK,VMS]				
MICRO	[DOS	][OS/2,UNIX,POSIX			MCA/EISA]

### Cost, CPU Platforms

It is expected that the cost/performance ratio for computing will continue to decline, perhaps even more dramatically than in the past. A cost/performance projection for various types of processors is presented in Table A6/A8-4.

**Table A6/A8-4 Cost \$1000/MIPS Trend**

	1988	1990	1992	1995	1999
SUPER	50	25	10	4	1
MAINFRAME	100	75	35	12	3
MINI	15-80	10-40	5-20	2-10	1-5
MICRO	5	2	1	0.5	0.2

### Mass Storage Subsystems

Disk and other mass storage strategies are undergoing significant revision in the wake of new optical storage developments. Storage devices using optical and hybrid opto-magnetic and vertical recording techniques are providing very large capacities at reduced cost, especially for archival applications. Table A6/A8-5 through Table A6/A8-8 demonstrate that other performance aspects of optical storage are converging on more conventional magnetic media.

While the present disadvantage of WORM optical disk systems is the slow average read/write access time (where separate erase and write cycles can consume a total of 200 - 500 msec), the media cost (of \$.20 per MByte) is significantly lower than magnetic tape and falling. Archival storage for SCS, including telemetry data samples, scenarios, and recordings of simulator training sessions, may present a substantial requirement. Within the next year or two, rewritable optical drive (ROD) products will offer rapid (30 msec) data storage/retrieval with GByte capacities to support high speed data representations within SCS. Optical disk technology is in its infancy and has performance deficiencies when contrasted with magnetic disk technology at this time. However, as optical disk technology matures, performance will increase to the level of magnetic disk technology, and may ultimately surpass it.

Mass storage strategies are appropriate to specific patterns of data utilization. Appropriate strategies will distribute these functions across the system hierarchy of linear buffering, addressable cache, extended store cache, memory, fast (magnetic)



disk, disk mirroring, slow (optical) disk, tape or other sequential storage, and optical or other archival media. Disk arrays may also be formed to improve reliability and combined access and transfer times. The SCS architecture, in order to preserve flexibility, would need to provide some redundancy of storage modes across real time and transactional levels of the system.

### Speed. Mass Storage

A projection for the access time of magnetic and optical mass storage devices is presented in Table A6/A8-5. Another important performance parameter, Disk I/O Transfer Speed is projected in Table A6/A8-6 in terms of MBytes/sec.

**Table A6/A8-5 Mass Storage Access Time (ms) Trend**

	1988	1990	1992	1995	1999
MAGNETIC	25	20	15	10	5
OPTICAL	80-150	50	30	10	5

**Table A6/A8-6 Disk I/O Transfer Speed (MBPS) Trend**

	1988	1990	1992	1995	1999
MAGNETIC	5	10	15	25	50
OPTICAL	5	10	15	25	50

### Capacity. Mass Storage

The mass storage capacity available on a single drive in terms of gigabytes (GB) is projected in Table A6/A8-7 for magnetic and optical disk technology. A gigabyte is equivalent to 1000 megabytes. Controller speed and capacity for number of devices does not vary greatly from one class of computer to another and is not shown. The compatibility of controllers across different media devices, however, could prove to be very important in the long run for the SCS architecture. Table A6/A8-8 contrasts this capability.

**Table A6/A8-7 Mass Storage (GB) Capacity Trend**

	1988	1990	1992	1995	1999
MAGNETIC	1	2	4	8	16
OPTICAL	20	100	200	400	1600

Versatility, Mass Storage

The interface between the CPU and the disk drive is an important component of system performance. Generally, proprietary controllers are used today. The use of standard interfaces between CPU and disk increased modularity and is encouraged. Table A6/A8-8 projects trends for Standard Disk Interfaces.

**Table A6/A8-8 Disk Interface Standards Trend**

	1988	1990	1992	1995	1999
MAGNETIC	[	ESDI, SCSI		]]	SCSI-2 ]
OPTICAL	[	None		]]	SCSI-2 ]

Cost, Mass Storage

The cost of mass storage is projected in Table A6/A8-9.

**Table A6/A8-9 Mass Storage Cost (\$/MB) Trend**

	1988	1990	1992	1995	1999
MAGNETIC	12	9	6	3	2
OPTICAL	5	3	1	0.7	0.4

### Video Subsystems

The salient alternative in video capabilities for SCS is the use of analog versus digital systems. Trends in both domains fail to suggest that commercial implementation of any major advances in video display technology will occur in the next ten years.

It is assumed that onboard SS video distribution is in an analog format. Where practical, SCS video from modulated signal sources including cameras, tape machines, and video disk players will easily approximate SS video systems and may use flight equivalent hardware. In these cases, hardware considerations will be driven by actual SS standards and requirements. In other cases where the approximation is only functional, current systems such as Super VHS should suffice. The development of HDTV should not alter the SCS configuration in this regard unless SS requirements are upgraded. Where detailed, rendered imagery is necessary for dynamic scenes such as EVA, animation from computer generated imagery may be necessary.

Realism in computer generated imagery comes at considerable cost in horsepower to accomplish the necessary coordinate transforms, hidden surface removal, surface shading, antialiasing, and other forms of rendering. In recent years workstations designed to support solids modeling have led the thrust in graphics technology. By 1990, however, the very fast raster drawing and shading capabilities of these specialized computers will be available at the single board level. This advance will permit an inexpensive box to offer high resolution real time animation, provided that the dynamics of the scene can also be calculated rapidly enough. Boxes utilizing new video chip sets from makers like Texas Instruments (340/440XX series), for example, could soon achieve rates of 100,000 Gouraud shaded polygons per second and still have 20 MIPS left over for scalar processing. This performance is projected to be available at a tenth the price of current workstations.

Display of video from stored sources such as digital video interactive (DVI) may also offer substantial performance. This performance is gained from the potentially rapid access under intelligent control of a large number of detailed image frames. The frames are formulated and written once. If visual scenes are predictable along some constraints, then frame sequences can usually be permuted at will. Capacities of

DVI disks are anticipated to rise substantially after 1995. Improved recording densities and compression techniques will account for the rise.

Chaotic compression (fractals) can achieve very high compression ratios on some scenes, but decoding is presently not executed in real time (best is four frames per second). The leading example of these systems, the Iterated Function System Image Synthesizer (IFSIS), is expected to be commercialized in the 1990 to 1992 time frame. Such products could reduce the data bit load by a factor of 1,000 to 10,000 depending on scene characteristics.

Standardization in this realm may prove to be a continuing problem unless compression is tied directly to the video mode and broadcast or media standard. This kind of standardization for computer generated imagery is less likely. Several recent attempts to forge standards (e.g., CORE and NAPLPS) have not achieved compliance, although powerful capabilities like object rendering may achieve de facto standardization through emerging graphics languages.

#### Speed. Video System

A projection of video frame drawing speed is presented in Table A6/A8-10.

**Table A6/A8-10 Frame Drawing Speed (Kpolys\*) Trend**

	1988	1990	1992	1995	1999
ANALOG	[ 30-120 Hz ]				
DIGITAL	50	200	500	1000	1000**

\* - 1000 Gouraud shaded polygons per second

\*\* - complex polygons

#### Capacity. Video System

A projection of video resolution in terms of pixels per screen is presented in Table A6/A8-11. The compression ratio trend is projected in Table A6/A8-12.

**Table A6/A8-11 Video Resolution Trend**

	1988	1990	1992	1995	1999
ANALOG	[ 440 x 335 ] [ 1275 x 720 ]				
DIGITAL	[1-16M pixels] [ 16-64M pixels ]				

**Table A6/A8-12 Compression Ratio Trend**

	1988	1990	1992	1995	1999
NTSC/PAL	[ NONE ]				
MAC-B	[	2:1	]	[	4:1 ]
HDTV	[ 20:1 ]				
DIGITAL	5:4	2:1	10:1	100:1	1000:1

Versatility, Video System

A projection of video format standards is presented in Table A6/A8-13.

**Table A6/A8-13 Video Format Standards Trend**

	1988	1990	1992	1995	1999
ANALOG	NTSC PAL SECAM MAC-B			HDTV HDTV HDTV HDTV	
DIGITAL	[ Vendor Proprietary Standards ]				

### Communications Subsystems

Network systems are presently evolving along several different lines of development. At the same time, networks are proving to be a critical factor in the architecture and design of modern real time and distributed cooperating systems. Consequently, the communication strategies, network topologies, access mechanisms, and hardware/software systems available for SCS design choices will probably determine much of its ultimate success. The following tables consider four general categories of networks: broadband; and baseband in three topologies: token ring, star, and bus link. (The categories tend to reflect vendor offerings more than technical distinctions because one could have, for example, a broadband star network.)

While Table A6/A8-14 through Table A6/A8-17 reflect a dramatic increase in the throughput of upcoming network systems, it is important to consider two facts. First, except for high fidelity representation of video data, the data flows of the SCS are not expected to demand such capacity or speed. Second, the SCS will make use of and be compatible with the SS Data Management System (DMS) architecture. Consequently, the SCS will support the DMS network operating system (NOS).

### Speed. Network

The network bandwidth for various network topologies is presented in Table A6/A8-14.

### Capacity. Network

The number of stations supported by the network is projected for various network topologies in Table A6/A8-15.

**Table A6/A8-14 Network Bandwidth (Mbps) Trend**

	1988	1990	1992	1995	1999
BROADBAND	600	1500	2500	5000	10000
STAR (fiber)	1400	1600	2400	3000	4000
TOKEN RING	4-16	100	400	1400	2400
BUS	400	800	800	800	800

**Table A6/A8-15 Number of Stations Trend**

	1988	1990	1992	1995	1999
BROADBAND	100's	100's	1000's	1000's	1000's
STAR (fiber)	10's	100's	100's	100's	100's
TOKEN RING	10's	100's	100's	100's	100's
BUS	10's	10's	10's	10's	10's

**Versatility. Network**

Access mechanism standards for networks are projected in Table A6/A8-16.

**Table A6/A8-16 Access Mechanism Standards Trend**

	1988	1990	1992	1995	1999
BROADBAND	[ SONET ]				
STAR (fiber)	[ Vendor Proprietary Standards ]				
TOKEN RING	IEEE 802.5 [ FDDI ] Future				
BUS	Ethernet 802.3, 802.4				

Cost, Network

Network costs in terms of dollars/Mbps/node are projected in Table A6/A8-17.

**Table A6/A8-17 Cost (\$/Mbps/Node) Trend**

	1988	1990	1992	1995	1999
BROADBAND	100	70	60	50	40
STAR (fiber)	300	250	170	130	90
TOKEN RING	600	200	70	50	40
BUS	200	100	100	100	100

System Interfaces

Interface requirements within the SCS include two primary types of hardware: (1) user interface devices including displays and controls for the simulated lab environment and the simulator control stations; and (2) equipment interface devices



such as digital-to-analog converters, multiplexers, actuators, et cetera. Requirements also include software and programming interfaces.

### Hardware

One aspect of SCS processing that could have a substantial impact on computing resource requirements is the conversion and compression of signals from high rate data sources. Both CPU generation and network communications requirements, as well as mass storage speed and capacity, for these data streams will be inversely proportional to the data compression and data filtering ratios achieved. Progress in hardware and software techniques for real time conversion is accelerating. Presently, proven techniques exist to compress audio data to 8 Kbps and NTSC video to 45 Mbps. At these rates, digitization and compression are expensive.

### Software

The software development environment for the SCS will be based on the SS Software Support Environment (SSE). This environment will provide a rich variety of development and analysis tools for system development. The appropriate selection and utilization of tools from that environment for SCS development is crucial to the overall success for SCS. Software paradigms and programming environments, like operating systems, will be very important to SCS's overall flexibility and its ability to interface readily with SS derived elements and potentially unique simulator subsystems like a payload stimulator or a highly automated scenario generator. Foremost in the SCS programming environment will be the capability of rapidly and accurately building payload simulation models which will interface in a modular fashion with the rest of SCS. These simulation models should be easy for both staff and principal investigators to construct. Object oriented design and programming systems that are expected to characterize the next generation of Integrated CASE tools offer an attractive platform for these efforts. Commercial object oriented data bases are being introduced which suggest that in a few years they could be effective vehicles for both model development and the actual real time implementation of SCS simulation. Object oriented systems also offer the distinct advantage (for meeting simulator production and evolution demands) of intelligently managed libraries of generically reusable code modules.

Other system software concerns include the emerging models for user interface standards. IBM's Systems Application Architecture (SAA) is an example of the kind of look-and-feel standardization which is expected to be prevalent by 1995. Combined with device independent terminal formats (such as X- Windows 11), general graphics languages, and common operating systems, the integration of different computer platforms into the SCS can be planned for within the initial architecture.

### SCS Architecture Requirements

The impact of technology developments on the SCS and architecture will be felt in those areas where the demands on computer resources are the greatest. Once training and operations requirements are compiled, SCS functional capabilities that

appear costly or difficult to implement using computing resources based on current technology can be identified. System level capabilities to be considered will include:

- 1) Automated simulator control and operation.
- 2) Real time dynamic simulation.
- 3) High fidelity representation of simulated entities and events.
- 4) Synchronized system-wide response to high rate and volume of simulation events.
- 5) System capacity and integration to simultaneously conduct multiple simulation scenarios.

The incorporation of new or advanced types of computing resources that could improve the implementation of selected SCS capabilities can occur in two respects. First, the availability of new products for SCS can be anticipated and included in the preliminary designs. Second, design decisions can be made, such as the implementation of a modular architecture, to maximize the system's ability to accept new components. The relative difficulty of uncoupling the original computing resource types and coupling in new types needs to be assessed for each function and subsystem implementation. In the final architecture formulation, these SCS expansion and replacement costs can be related to the performance gains expected from using each candidate computer resource advancement.

### Results

Based on the above analysis of future trends for computing technology, the following candidate requirements are presented:

1. SCS system components will be designed in a modular fashion so as to allow upgrades and enhancements to the SCS to be made easily.
2. SCS software components will be developed with SSE.
3. SCS system components will be compatible with DMS network operating system (NOS).
4. The SCS will implement standards used by the Space Station, where possible. Where no SS standard is available, industry standard protocols, systems, and interfaces will be used.
5. The SCS operating system used by the host processors will be portable, have real time features, and be based on an industry standard.
6. The SCS will be designed to anticipate advanced technology insertion.

### Open Issues/Notes

**Study Title: Implications of Simulation Development Cycle****Study No. A-7; Report Version 2****Problem**

To define the simulator development load on the SCS, we must expand on the analysis done as part of the effort captured in the SCS Study Issues Report. Assessment of the development load is key to sizing the SCS system. The development load and training load will constitute nearly all, if not all, of the loading on the SCS system. The third function, Operations Evaluation, is expected to be largely performed as part of training, and will thus contribute only a very small additional load to the SCS system.

**Approach**

Analysis of the training flow has been completed and baselined as part of study T-1. Based on the training flow, and code size estimates, the development flow and size will be derived. Other approaches will be evaluated, and if applicable will be utilized as a second method of arriving at the SCS development load.

**Analysis Overview**

The training flow as summarized in study T-1 was utilized as were the code sizes from T-1. Assumptions from the SIR report were used to calculate the code under development at any point in time. The last paragraph discusses a second size estimate based on past Spacelab experience.

**Inputs**

1. Study T-1 PTC Training increment Flow Requirements.
2. SCS Study Issues Report, 19 December, 1988

**Assumptions**

11. Payload change out per increment will be a worst case of 15% per increment.
12. Payload simulations are software simulations 90% of the time.
13. Development will be done concurrently with training on the day shift. Swing and midnight shifts will be reserved for PM, CM, and backups.

**Analysis**

The PTC Training Increment Flow Requirements (Figure T-1.1 in Study T-1) shows four crews and the POIC cadre training at the PTC simultaneously. This figure is the base for the training flow and load in the SCS. The development load is overlaid on this to produce the PTC Training Increment Flow Requirements, with

Simulator Development Overlay (Figure A-7.1). The development overlay is derived from the Single Medium Complexity Experiment Development Cycle (Figure A-7.2) on the next page. It is estimated, based on the SCS team's combined software development experience, that this medium cycle represents a good average. Complex simulations will no doubt take 3 to 4 months longer, and simple experiments may take 3-4 months less time to develop. But overall, an 11 or 12 month simulator development cycle seems correct.

Graphic analysis using the Development overlay chart shows that, using this 12 month average, that all four development phases will be in progress (for different increments) at any one time. Our assumption of a maximum of 15% change out per increment, and our 90% software simulations means that ongoing development will be the size of 54% of a single US Lab/attached payload increment. Utilizing the software sizes for payloads from T-1 yields a total US Lab/attached payload simulator development code size of:

#### Line of Code

7 complex models =	242,900
10 medium models =	220,000
26 simple models =	185,900
US Lab + AP Total	<u>648,800</u>

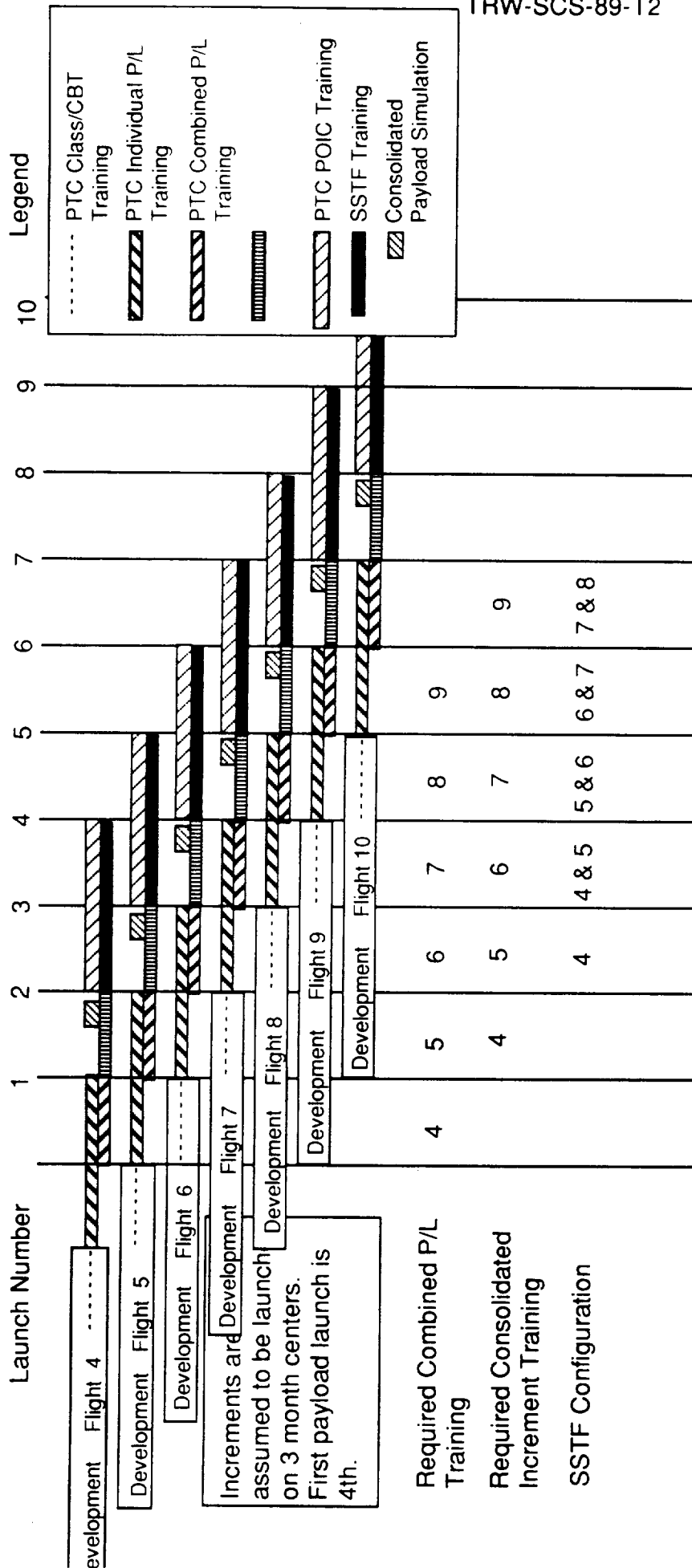
This number of lines is then then multiplied by 54% to yield the number of lines of code under development at any given time on the SCS:

350,352 Lines of code under development

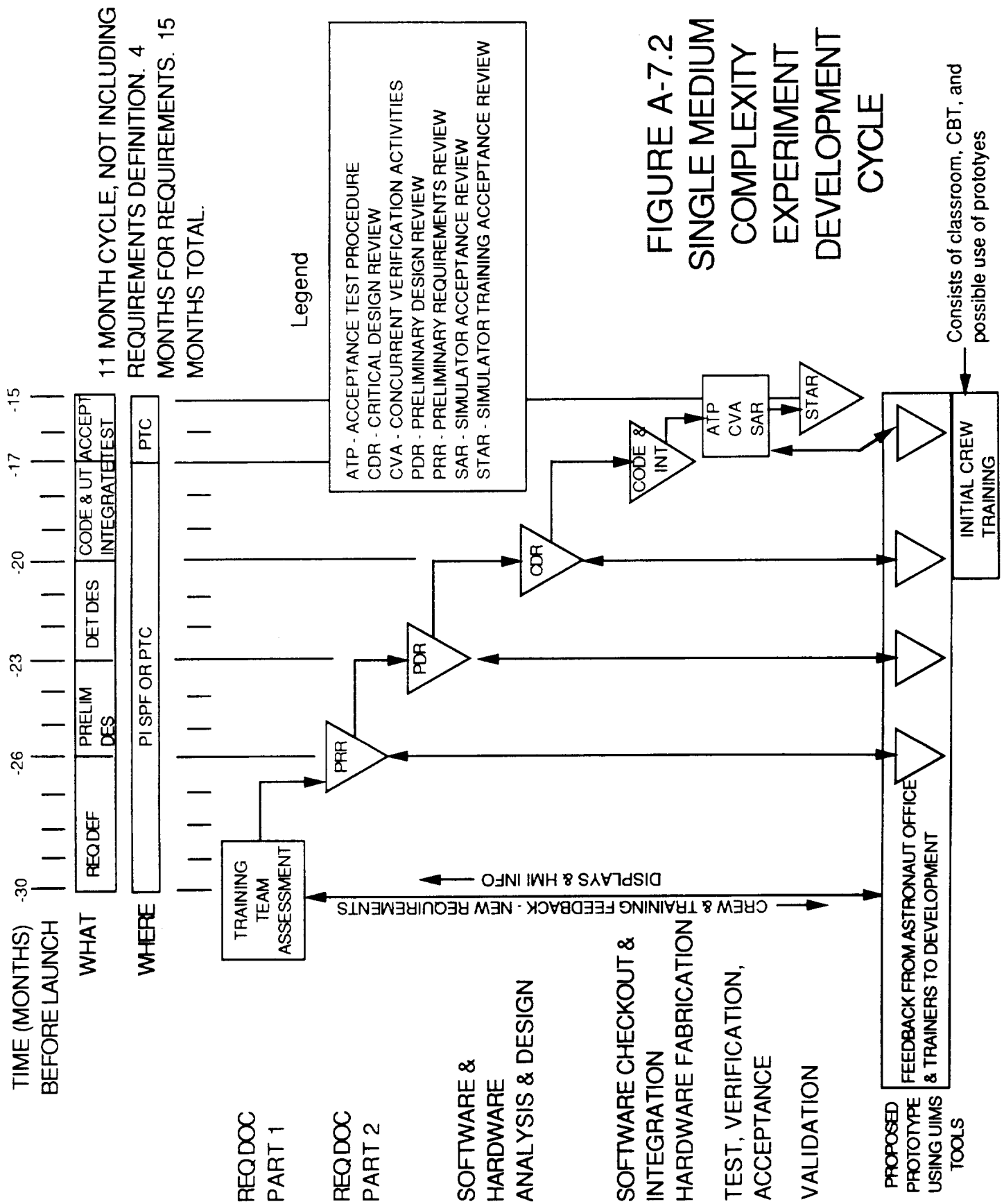
Using 150 lines of code per MM, and 12 MM per MY, yields 1800 lines of code that can be developed in one man year. Given that this cycle is one year long, this yields:

$350,352 \text{ LOC} / 1800 \text{ LOC per developer} = 195 \text{ developers}$

This means that 195 developers would be needed at all times, and all these developers would be using the SCS for preliminary design (CASE tools, word processors, chart making tools), detailed design (PDL tools, CASE tools, chart making tools), code (editors, generators, and compilers) and unit test (editors, generators, compilers, test building tools, debuggers, unit test runs), and acceptance testing (I&T tools, I&T runs, V&V tools, V&V runs, CM tools).



**FIGURE A-7.1 PTC TRAINING INCREMENT FLOW REQUIREMENTS  
with SIMULATOR DEVELOPMENT OVERLAY**



Spacelab historical perspective and plans are a different way of looking at this problem. Spacelab has about 30 simulator developers, and this team has sustained an actual flight rate of approximately one flight per year of 8 to 12 payloads per flight. Given 43 payload to be simulated for one SS US Lab increment, a change out maximum of 15% assumed per increment, and a flight rate 4 times that of Spacelab means that the PTC must develop approximately 3.5 times the number of simulators produced by Spacelab in one year. This yields:

$$30 \times 3.5 = 105 \text{ developers}$$

### Results

This analysis shows that the SCS development host and/or SPF must be able to support between 105, and 195 software developers running concurrently with training.

### Candidate Requirements

1. The SCS system shall be able to support development of all the software (90% of the total number of PTC simulators) simulations needed to support the required PTC training flow.
2. The SCS shall have the required computer speed and capacity to support this development during the same hours as the training function is performed, with no significant (less than 10%) degradation from the stand alone speed or performance of the development tools.

### Open Issues/Notes

**Study Title: Fidelity of DMS Interface****Study No. A-10;****Report Version: 1****Problem**

This study will examine the required fidelity of the DMS interface for the SCS. At issue is whether a DMS kit is required for high fidelity payload simulation and training, or whether a DMS simulator could provide sufficient fidelity for payload training.

**Approach**

The DMS requirements will be analyzed through study of the architecture control documents, presentations, and discussions with the developers and the training community.

**Analysis Overview**

The DMS requirements are presented in a summary fashion. The structure of a payload experiment or model is analyzed to determine the required DMS services from the viewpoint of the experiment or model. In addition, the DMS interface requirements to SS core services are discussed.

**Inputs**

1. SSP 30261, Rev B Architectural Control Document, Data Management System
2. DMS Baseline, J. N. Dashiell, Nov. 29, 1988
3. Data Management System Concepts, J. T. Spainhour, Boeing, Mar. 17, 1988
4. Simulator/Trainer/Mock-up Classification, Dennis Dahms, Mission Operations Directorate, Nov. 15, 1988

**Assumptions**

14. The PTC will not be responsible for any subsystems training. The PTC will utilize the minimum subsystem interfaces required to support payload training.
15. The PTC will use NASA-provided DMS kits.
16. A host-based DMS functional simulation (FSIM) to be provided by SSE will not run in real time. Thus, FSIM is assumed to be of minimal utility in the SCS.



## Analysis

The Data Management System (DMS) provides the computational, storage, data acquisition, user interface, and network resources for the Space Station. All electrical systems, including payloads, interface to the DMS. In addition to hardware resources, the DMS includes standard software services for SS systems, and operations management services through the Operations Management System (OMS) and the Operations Management Application (OMA). A summary of the DMS components is given below.

### DMS Components

#### Hardware

Standard Data Processor (SDP)

Mass Storage Unit (MSU)

Multiplexer/Demultiplexer (MDM)

Embedded Data Processor (EDP)

Network Interface Unit (NIU)

Bus Interface Adapter (BIA)

Bridge

Gateway

Multipurpose Application Console (MPAC)

Time Generation System (TGS)

Networks

#### Software

Standard services used by applications

Operating System

Network Operating System

User Interface Management System (UIMS)

Data Storage and Retrieval (DSAR)

Integration, Test, and Verification (IT&V)

Fault Tolerance and Redundancy Management

Data Acquisition and Distribution Services

MPAC Workstation Services

User Interface Language (UIL)

Management services for the DMS and the Space Station

Operations Management System (OMS)

- Short-term planning

- Coordination of the short-term plan

- System and payload status monitoring

- Management of inter-system and payload testing

- Logging of global configuration and activities

- Management of global base Caution and Warning

- Global base fault management and reconfiguration

- Support of command and uplink/downlink management

- Global base inventory management

- Support of onboard simulations and training

### Payload Applications

All onboard applications, including payload applications, utilize the DMS system components and services. Flight equivalent payload applications reside in one of three places; a SDP, a EDP within a MDM, or another processor interfaced to a MDM. To communicate with the experiment or the operator through the MPAC, the payload application makes use of the DMS standard services. Communication with DMS standard services generally consists of calling or being interrupted by the service desired and passing parameters.

A part of the payload application, the user interface, must also reside on, or be accessible to, the MPAC. Through the user interface, the operator controls the experiment. This is accomplished by exchanging messages between the MPAC and the payload application. The experiment can also be controlled through the experiment control and display panel.

Software models can also be used to simulate the payload application. The software model uses the DMS services, like the flight equivalent experiment, to provide a high fidelity representation of the payload. A software model can also be used to stimulate the payload model through the MDM to simulate the SS environment. This software model of the payload can be executed from a variety of platforms including a SDP, a EDP within a MDM, another processor interfaced to a MDM, or a simulation host computer.

To maintain the required high level of fidelity, it is preferable to utilize the flight articles for training. However, it is anticipated that the flight articles may not be available for training on the first few launches. The development of software payload models of experiments is a significant undertaking, in terms of cost and time. If software models are to be developed for training, it is critical that the software models developed for the experiment be used throughout the training cycle. In other words, the same software model should be transportable between the Part Task Trainers, the Element and Module Trainers at the PTC, and the payload trainers at the SSTF.

The transportability of software models between the various training facilities has implications on the fidelity of the DMS. While not all DMS services are required for flight equivalent payloads, payload models, and all training environments, those DMS services and applications which are used must be of sufficient fidelity to allow transportability of payload models. If these requirements are met however, a software simulation of the DMS, instead of the DMS kit, could be used for training. However, to insure transportability between facilities, DMS Kit hardware and software must be utilized.

In the Part Task Trainer, interactions between the SS core systems and other payloads are of lesser importance. Rather, the Part Task Trainer provides the operator early training about payload-specific operations. Thus, for some of the PTTs, a high fidelity software simulation would suffice. In the later phases of training, when the payload training has been moved to the Combined and Consolidated trainers, interactions between the experiment, other payloads, and the SS core systems become more important. Thus for the Combined and Consolidated trainers, DMS Kits should be utilized.

The required fidelity of a DMS simulation is therefore dependent on the training environment in which it is to be used. A DMS simulation within a Part Task Trainer would be required to model at a high fidelity only those DMS services required for early payload training. Other DMS services could be modeled at a low fidelity level or omitted entirely.

## Results

The above analysis lead to the following candidate requirements:

1. Flight equivalent payloads and software payload models will be transportable between the Part Task Trainers, the Element and Module Trainers at the PTC.
2. The Part Task Trainers will be used for early training, and payload-specific training.
3. A simulation of the DMS may be utilized in the PTTs, provided that payload models developed with it can also be used with a DMS kit, and that sufficient fidelity to provide good payload training is provided.

**Study Title : The Definition of No Single Point of Failure****Study No. A-11; Report Version 2****Problem**

This issue involves the level of need for backup for every SCS component, and the consequent cost of not having a backup for every component, i.e. no single point of failure.

**Approach**

The approach to researching this study was to examine the availability and reliability requirements of simulators with a purpose similar to the SCS simulators.

**Analysis Overview**

The analysis for this study provides a definitions of reliability, availability, and maintainability (RAM), and presents the RAM requirements for no single point of failure.

**Inputs**

1. Requirements specification document for the Computing Development System (CODES), a TRW study performed for the U. S. Army Strategic Defense Command.
2. Requirements document for SSTF software development facility for Spacelab payload simulation.

**Assumptions****Analysis**

This study investigates the interpretations of reliability, availability, and maintainability. The information was acquired by examining the SSTF requirements document, utilizing the TRW produced Computing Development System (CODES) requirements specification document, and personal interviews with TRW personnel who are currently using the Software Development Facility Extension (SDFE) for Spacelab payload simulator development.

No single point of failure is an extremely important issue from the training viewpoint. It is important that the PTC be able to conduct its training programs without significant impact due to system hardware failures. In most cases, the schedules of the personnel involved in training will be booked solid far in advance, which will make it expensive to reschedule a training session that has to be canceled due to a facility problem. Training exercises that involve experiment team representatives with the crew and ground operations cadre may involve travel for a large number of the participants that cannot be rescheduled without significant costs to the program.

Thus, the basic issue here is the cost of backup hardware vs. the cost of lost training time for a system which has many single points of failures.

Discussions and analysis have pointed toward an alternative to specifying no single point of failure. This is specifying the SCS in terms of "ilities" to minimize the cost and impact on training of system failures. Other training systems have used this approach. It is an appropriate requirements solution, since the performance of both hardware and software are bound by three "ilities": reliability, availability, and maintainability. The applicable definitions for all three follow.

**Reliability** - System reliability is the extent to which the system will perform a required function under stated conditions for a stated period of time. Reliability can be determined by the following formula.

**Reliability = (No. of successful applications)/(No. of attempted applications)**

**Availability** - System availability is the portion of total operational time that the system performs or supports simulations. Availability can be calculated using the following formula.

**Availability = (MTBF)/(MTBF + MTTR)**

where MTBF is mean time between failure and  
MTTR is mean time to repair.

**Maintainability** - System maintainability is the effort required to locate and correct a fault in the system. Since the payloads will be software intensive, the software design and the completeness of the operating manuals will greatly affect the maintainability of the system.

The minimum requirements for the SCS simulators with respect to reliability and availability will correspond to the values contained in the table below. The values in table are representative of the time when the system is required to be active and not real clock time. The values were determined by researching simulators and documents with similar purposes. The simulators include the SDFE and SSTF and the documents included the TRW CODES study.

<u>Reliability</u>	<u>MTBF</u>	<u>Availability</u>	<u>MTTR (HW)</u>	<u>MTTR (SW)</u>
98 %	270 hrs	97 %	8 hrs	8 hrs

The MTBF values specified will be achieved during acceptance testing. The MTBF measure will be the estimated cumulative MTBF for the hardware and each software function during the last third of the acceptance test.

In order to satisfy the requirement for reliability, availability, and maintainability, it will be necessary for the SCS to exhibit certain design characteristics and attributes. These design characteristics and attributes are identified below.

- The design should be such the any single component failure does not affect the ongoing operations of all other components.
- The design should allow maintenance to be performed on a failed component during normal operating hours and it should allow a repaired component to be reinstalled to operational status without impacting the remaining operations.
- All scheduled preventative maintenance should not interfere with normal working operations and preventative maintenance should be a minimum of 32 hours/month and a maximum of 40 hours/month.

### Results

1. Reliability for the SCS simulators shall be 98 %.
2. Availability for the SCS simulators shall be 97 % with MTBF (270 hrs) and MTTR (8 hrs for either hardware or software or 1 training day)
3. The SCS simulators shall exhibit the following characteristics:
  - The design shall be such the any single component failure does not affect the ongoing operations of all other components.
  - The design shall allow maintenance to be performed on a failed component during normal operating hours and it shall allow a repaired component to be reinstalled to operational status without impacting the remaining operations.
  - All scheduled preventative maintenance shall not interfere with normal working operations and preventative maintenance should be a minimum of 32 hours/month and a maximum of 40 hours/month.

### Open Issues/Notes

## SCS Study Analysis Assumptions

1. A worst case load on the SCS is assumed for payload models which might be simulated by either physical hardware or a simulator executing on the PTC SCS.
2. Code size estimates are based on Spacelab experience using structured analysis and FORTRAN coding. These estimates may be reduced using new CASE tools and new programming methodologies.
3. OMS functionality with respect to the onboard application (OMA) will be provided by the flight software resident on the DMS kits. OMS functionality with respect to the ground application (OMGA) will not be a part of the DMS and will have to be provided by other means.
4. A worst case load on the SCS is assumed for subsystem models which might be required to support payload training.
5. The SCS ECWS is not required to provide the nonpayload related functionality of the flight equivalent ECWS. However, the flight equivalent ECWS may be used for the SCS ECWS.
6. The SCS video system will be compatible with the video subsystem of the SS Communications and Tracking system.
7. The SCS video system will be capable of interfacing to the SSIS network.
8. The SCS video system, while compatible with the SS video subsystem, is not required to provide 100% of the functionality of the SS video subsystem.
9. SCS video data is not required to be digitized and sent through the C&T system to the POIC.
10. Late changes to the simulators are a problem that the PTC/SCS people have to solve.
11. Payload change out per increment will be a worst case of 15% per increment.
12. Payload simulations are software simulations 90% of the time.
13. Development will be done concurrently with training on the day shift. Swing and midnight shifts will be reserved for PM, CM, and backups.
14. The PTC will not be responsible for any subsystems training. The PTC will utilize the minimum subsystem interfaces required to support payload training.
15. The PTC will use NASA-provided DMS kits.

16. A host-based DMS functional simulation (FSIM) to be provided by SSE will not run in real time. Thus, FSIM is assumed to be of minimal utility in the SCS.

*End Date June 1, 1990*



